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Thesis

AIRPLANES AND THEIR ENGINES

by

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INTRODUCTION

PURPOSE OF THE THESIS

Early in the eighteenth century man began scientific investigation of the possibility of heavier-than-air flight. Even before man's first flight at Kitty Hawk, North Carolina, in 1903, much valuable scientific information concerning the theory of flight was available.

Success stimulated these investigations which are now being carried out on a broad front throughout the entire world, but there are yet many problems to be solved.

The design of airplanes has been reduced to a more or less exact engineering problem and we find therefore that continued improvement is dependent upon the solution of certain more complex problems in the theory of flight, structural design, and engine operation. In an effort to solve these problems we find the Federal Government, the universities and the manufacturers engaged in extensive research, and this research is supplemented by that of foreign countries. Due to the fact that science recognizes no international borders, much of this information is freely exchanged.

Perhaps the most notable contributions in the United States at the present time come from the National Advisory Committee for Aeronautics, sponsored by the Federal Government, which maintains laboratories at Langley Field, Virginia. Here we find not only a staff of highly trained experts, but also a full scale wind tunnel in which full size airplanes may be mounted and their flight characteristics studied in great detail. Here also we

find a spinning tunnel in which the dynamic factors controlling spin may be determined.

With respect to the airplane engine, we find that the Bureau of Standards at Washington has conducted a large number of experiments for the purpose of solving some of the problems of the internal combustion engine. These tests have resulted in many improvements tending toward refinements in design and operation.

The aeronautical engineering departments of the many universities throughout the United States have also contributed very materially to the art, and at the present time we find much worthwhile research work being done in their laboratories.

A little closer to the practical side we find the laboratories of the manufacturers, not only of the airplane and the engine, but of all the many auxiliaries which make up the completed airplane. The manufacturers are naturally particularly interested in the practical phases of design, but we find nevertheless that their engineering departments are staffed with exceedingly skilled research men who have contributed in no small measure to the general advancement of the science.

An immense amount of literature from the many sources described above has been published, and this must be read if a complete picture of the state of the art at the present time is to be obtained. As may be expected, the individual laboratories usually concentrate on a few problems and we find therefore a large number of publications concerning disassociated phases of the science.

It is the purpose of this thesis to integrate all of this mass of material and to extricate from the many sources available information pertaining to the modern airplane in order that the reader may, without the expenditure of a considerable amount of time, have a clear picture of the principles of operation of the airplane and its engine.

In order to provide a background, this paper includes a short introductory section dealing with the history of aeronautics as well as a description of a number of types of airplanes used at the present time.

Since the material in this thesis has been obtained from many sources, footnotes and references would make this paper quite cumbersome, requiring in some cases as many as ten or a dozen references for a single item. For this reason the references used are consolidated in the last section.

Diagrams shown are original, while pictures are photostats of manufacturers illustrations.

HISTORICAL SKETCH

A knowledge of the history of any art is essential to inventor, builder and student since it helps them direct their efforts more intelligently toward the goal for which they are striving.

We think of the present radial aircraft engine with its cylinders radiating from a central crank case as comparatively modern. However, we find that as far back as the Spanish War

Charles M. Manley had invented and built a radial type internal combustion engine which had five cylinders, developed sixty-two horsepower, and weighed two and two-tenths pounds per horsepower. This engine compares very favorably in weight with present day radial engines of the same size.

Similarly, we find in history many devices discarded as impracticable which are now coming into general use in the ultra-modern airplane. The most notable of these is the three-wheeled under-carriage which up to the time of the World War was used on many airplanes and then discarded. Last year it again made its appearance and is probably here to stay.

The Wright brothers' catapult is another example of a discarded device which is now being used in launching airplanes where take-off space is limited.

Aviation dates back to the fourth century before Christ, and accounts are available of the supposed flight of a wooden pigeon built by Archytas, a "learned man of Taranto." Records do not disclose whether this wooden pigeon actually flew but it was at least a start. From the beginning of time man has enviously regarded the flight of birds, and the feeling of the earlier inventers is expressed very nicely in Hodgins and Magoun's SKY HIGH:

> Early in the march of civilization man found that he had conquered two elements. The land and the water were his to travel on, but the invisible and mysterious air he could not conquer. His triumph was incomplete. For this reason the birds annoyed him. They made flight seem so easy and effortless. They could soar and he could only envy. To cover up this envy he convinced himself that the ability to

> fly was supernatural. He built up pleasant fables of winged horses, magic carpets, and flying gods.[1]

Even within the author's memory the phrase, "You can't do that any more than you can fly" was quite common.

Man first ascended into the air by the use of a balloon, and there are many accounts of balloon ascensions, first using hot air, and following this, hydrogen. When the first balloon capable of lifting its own weight actually rose into the air the first step in the conquest of the air was taken. Later, as balloons were increased in size and hydrogen substituted for hot air, they became sufficiently buoyant to lift man. The first balloon passengers of history were a sheep, a rooster and a duck. This flight occurred in 1783, and was followed by a series of balloon flights which lasted up until 1785 when DeRozier's attempt to fly across the English Channel resulted in the first major catastrophe in aeronautics. Records show that on June 14, 1785, this balloon rose from the south of France, and approximately half an hour after the ascension had taken place the spectators were horrified to see the balloon burst into flame. This accident checked for a time the development of the balloon and man turned his attention to mechanical flight.

The Wright brothers' first powered flight at Kitty Hawk

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[1] Hodgins and Magoun, Sky High (Boston: Little Brown and Company, 1925), p. 3

in 1903 was the result of more than a century of preparatory work by many famous men.

Sir George Cayley, in 1809, first suggested the use of fixed planes driven through the air by means of propellers.

John Stringfellow, in 1848, constructed the first successful powered airplane model. This model had a wing spread of ten feet and was powered with a small 2" x 3/4" steam engine which he had built himself. This model flew a distance of sixty-six feet on its first flight--not a great distance, to be sure, but at least it proved that mechanical flight was possible.

Alphonse Penaud was one of the first men to give consideration to the stability of airplanes in flight. He recognized such things as the relationship between the center of gravity and the center of pressure, which relationship was later found to be of prime importance. He also stated that in order to fly, an airplane would have to weigh less than eighty-one pounds per horsepower, and it is noteworthy that no successful airplane has ever exceeded this weight. Penaud died in 1880 and the world lost a truly brilliant mind.

In this rapid review the names of many who contributed to the science of aviation have been omitted, but we cannot pass without mentioning Horatio Phillip, who first appreciated the importance of the shape of wings. While other experimenters did not realize the inefficiency of flat wings, he tested numerous thick section wings in a crude wind tunnel which he himself built. He was born in 1845 and died in 1912.

Then followed in rapid succession Sir Hiram Maxim, Octave Chanute, Otto Lillienthal, Professor S. P. Langley, Charles M. Manley and finally, the Wright brothers--the first to launch man successfully into the air in a powered heavier-than-air craft.

After the Wright brothers' first successful flight, the news of which was received with some skepticism by the general public, aviation advanced rapidly with the achievements of such men as Santos-Dumont in France, who made the first recorded airplane flight in Europe; Glenn Curtiss in the United States, who manufactured the first seaplane; Louis Bleriot who flew the first monoplane, was first to fly the English Channel, and first to demonstrate the practicability of equipping airplanes with landing wheels; Leon Delagrange, the first pilot to carry a passenger; Henry Farmam who in 1908 became the first cross-country pilot, flying a distance of seventeen miles from Bouy to Reims; and many others.

Thus, at the time of the outbreak of the World War the airplane was definitely established. During the early stages of the war it was used merely for observation purposes. Soon, however, armament was added and the service of the airplane was extended from reconnaissance to photography, artillery fire control, fighting, and bombing. The World War gave the airplane a tremendous impetus and undoubtedly accomplished in four years as much as had been achieved in a decade of previous development. After the war there was a stagnant period due to a surplus number of military airplanes.

The use of airplanes for transport, however, gave a new incentive to the aircraft builders. Here was a new type of service for which the surplus war airplanes were entirely unsuited --the carrying of passengers and cargo over considerable distances. The high speed pursuit plane of the World War now became a slow airplane. Commercial airplane speeds skyrocketed at an amazing rate due to the competition of the airlines.

In the study of the history of the development of the airplane, certain flights stand out as being particularly significant with respect to the advancement of the art. Regardless of how spectacular a flight may be, unless it contributes to the art it is of no particular significance to the science of aeronautics.

Stringfellow, who in 1848 constructed the first successful powered model airplane, contributed more towards science than many spectacular flights, the accounts of which have been blazoned across the front pages of the newspapers throughout the world. However, flights which break records are desirable since they indicate the advancement of aviation and they unquestionably stimulate its further advancement.

Today we find hundreds of airplanes shuttling between cities with clocklike precision at amazing speeds. Millions of passengers are flown millions of miles per year, and air transportation is still in its infancy.

TYPES OF HEAVIER-THAN-AIR CRAFT

Heavier-than-air machines, or aircraft, as they are usually called, may be divided into four classes: ornithopters, helicopters, airplanes and autogyros.

The Ornithopter

It was natural that man's early efforts toward heavier-than-air flight would be directed towards imitating the birds. History records many such attempts and even now inventors occasionally attempt to build this type of craft.

Early builders were, of course, hampered by the lack of a suitable power plant. The first machines were designed to be operated manually but thinking men soon found this to be impracticable since man, because of his physiological make-up, is unable to expend energy in proportion to his weight at the same rate as the bird. A bird's muscles represent approximately one-sixth of his weight while man's muscles represent only one one-hundredth part of his weight.

The advancement of an art comes usually through the application of the power of the mind. What man can conceive he can also accomplish providing he proceeds intelligently.

Ornithopters are heavier-than-air craft which fly by means of flapping wings, and it was with this type of heavier-than-air machine that man first attempted to conquer the air. However, considering the ornithopter after these many years of scientific development, it can be seen that the principle used is basically wrong.

Of all man's inventions probably none has had a greater effect on the world of today than the wheel. There is no part of our present day existence which is not dependent in some way or another upon this very simple device. Every mode of vehicle and almost every type of machine would not be in existence if it were not for the wheel. We find, also, that where man has succeeded in using the wheel he has, in nearly every case, improved upon the mechanics of nature. As an illustration: A man can go much faster under his own power by the use of a bicycle than by walking since the reciprocating motion of his feet and legs has been replaced by rotary motion. Similarly, propellers for boats are superior to oars, and steam turbines provide better power plants than reciprocating steam engines. The airplane has thus improved upon the flight of birds through the use of the propeller, which is essentially a wheel, and we would therefore expect that the ornithopter, even had it been successful, would be inferior to the present day airplane because of the reciprocating motion of its wings.

In the study of the various ornithopter designs proposed, some of which were actually built by designers, it is found that in order to provide reciprocating motion for the wings, enormous amounts of power were required, as well as very rugged structure, and a large proportion of ornithopters that have been built, when tested, have remained on the ground, literally shaking themselves to pieces in an ineffectual attempt to fly.

The Helicopter

The designers of helicopters have been more successful. Here the rotary principle is applied through the use of propellers, the purpose of which is to lift the helicopter vertically into the air. The successful helicopter, however, is of comparatively recent design. For many years man despaired of ever being able to rise vertically into the air. Many famous scientists have experimented with propellers with the intention of applying them to helicopters without success. The helicopter must be equipped with two propellers since the application of power to a single propeller results in a torque which causes a turning moment in a direction opposite to that in which the propeller itself is turning.

This principle also holds true in the airplane, making it necessary to build into the airplane certain characteristics which prevent the airplane from rotating in a direction opposite to that of the propeller.

A helicopter with a single propeller, once off the ground, would immediately start turning in a direction opposite to that of the propeller, and for this reason it is necessary to equip the helicopter with two propellers turning in opposite directions in order that the torque of one might offset the torque of the other.

One of the hazards of helicopter flying is that should the engine and propellers stop turning, no lift would be available to keep the helicopter in the air and it would immediately fall.

It has, however, one advantage over the airplane in that it can rise vertically, whereas its disadvantage is that, unlike the airplane, it cannot remain in the air by gliding, once the motor stops. However, Cierva's development of the autogyro, in the meantime, has eliminated this hazard.

In the latest type of helicopter demonstrated in Germany in 1938 the principle of the autogyro is incorporated in such a way that should the motor fail after take-off, the propellers are disconnected from the engine and continue to rotate freely, and the helicopter is thus able to glide to the ground very much in the same manner as the autogyro.

The Airplane

The third type of heavier-than-air craft, the airplane, will be discussed in detail later.

The Autogyro

The fourth type is the autogyro which consists of a standard type airplane fuselage or body with an engine and propeller in the front end, the purpose of which is to pull the autogyro through the air in exactly the same manner that the airplane is pulled through the air.

Cierva, the father of the autogyro, was of the opinion that it would be better to obtain the lift on an airplane wing by rotating the wings rather than to cause the wings to move through the air at a high speed. For this reason he altered the shape of the wings so that they consisted of either three or

four long blades which rotate about a bearing located above the fuselage or body. These blades are started initially by a drive shaft connected to the engine by a clutch, and upon reaching a proper rotational speed, about one hundred and sixty revolutions per minute, the clutch is disengaged and the autogyro then takes off in exactly the same manner as the airplane.

It is to be noted that there is no mechanical connection whatsoever between the engine and rotor blades in flight, and the air forces acting on the blades provide the motivation which causes the blades to continue rotating while the autogyro is in flight. This is the essential difference between the autogyro and the helicopter. In a helicopter the propellers are driven by the engine at all times, whereas in the autogyro the blades rotate freely of their own accord. Should the engine of the autogyro fail, the pilot merely pushes the stick forward, the nose drops and the autogyro begins a gentle glide for a landing.

There is one thing, however, that the autogyro pilot must be very careful not to do, and that is to open the throttle suddenly when near the ground, since then engine torque would cause the autogyro to tip in a direction opposite to that in which the propeller is turning, and damage may result through the rotor blades striking the ground.

GENERAL DEVELOPMENT

Airplanes for transport service have become quite commonplace. This is only natural since transport planes are in evidence in every port of the world, flying their schedules day in and day out with clock-like regularity. The transport industry has grown by leaps and bounds in the last ten years, until now the United States is covered with an extensive network of airways along which some nineteen major airlines fly between sixty and seventy million miles per year, carrying approximately a million passengers. These same airplanes also carry some millions of pounds of express and mail.

In addition to our domestic services, the airlines have extended their routes from the northern tip of Alaska to the southern tip of South America, westward to China and the Philippines and eastward to Bermuda. Test flights are now being conducted for the purpose of linking the United States and Europe by air.

In addition to transport service we find airplanes used for

- Photography
  - Advertising
  - Scenic reproduction
  - Mapping

- Crop Dusting

- Advertising
  - Sign Towing
  - Sky Writing

- Ship to shore ambulance service (Coast Guard)

- Student instruction

Private transportation of executives

Exploration

Meteorology

Flood survey and rescue work

Forest fire patrol

Fish and game patrol

Police duty

This partial list of extra services indicates how the use of the airplane has expanded. Actually, private airplanes fly fifty percent more miles and carry many more passengers than do the airlines. Yet with all this flying not over one percent of the one hundred and thirty million people in the United States have ever flown. It is evident from these figures that should this one percent by increased to five percent within the next ten years, not an unreasonable assumption, the aircraft industry must expand five-fold.

The growth of an industry can often be studied by considering the development of employment conditions within that industry.

The operation of the aircraft industry, both on the ground and in the air, has changed considerably in the last twenty years. During the period of the so-called barnstorming pilot, who flew from town to town in a reclaimed war-time airplane, the pilot serviced his own airplane, that is, he kept it in repair, did his own advertising, collected the fares from such passengers as he was able to induce to fly, and regulated his own

itinerary. Barnstorming pilots were found in all parts of the United States, and they formed the nucleus of our present extensive aircraft industry. Since this time, however, the operation of aircraft has become more complex, and it has become necessary for the aircraft industry to employ many specialists in many different branches of the industry.

As aviation grew it was realized that for the protection not only of the general public but also the pilots themselves some form of Federal regulation would be required, and the Air Commerce Act of 1926 placed the aircraft industry under such Federal control. This control was centered with the Bureau of Air Commerce of the Department of Commerce. Rules and regulations concerning the design, manufacture, operation and maintenance of aircraft were laid down and we find that this regulation was the beginning of real growth in aviation.

The Bureau of Air Commerce was superseded in 1938 by the Civil Aeronautics Authority under the Civil Aeronautics Act of 1938, which act contemplates a "comprehensive program of Civil Aviation to be integrated in the national defense program." Thus we find that at the present time the aircraft industry in practically all of its phases is controlled by certain rules and regulations promulgated not only for the general welfare of the public but for the industry itself.

In order to obtain a comprehensive picture of the aircraft industry it would be helpful to follow an airplane from the drafting board to the finished product.

Assume that some manufacturer desires to produce a new type of airplane for which he feels there is a demand. The designer is put to work with the general specifications as drawn up by the manufacturer and designs an airplane to meet these specifications.

It is interesting to note that even before an airplane is constructed the designer is able to compute its performance, that is, its top speed, rate of climb, landing speed, and other general flying characteristics.

Before the airplane is completely designed, a stress analysis must be made to determine the size and the strength of the many individual parts of the airplane, and this requires many hours of careful computation. The stress analysis and design are then submitted to the Civil Aeronautics Authority for approval, and this approval very often is predicated upon certain recommended changes in the design. After these changes have been made, and the final design and stress analysis approved, shop drawings must be made. The airplane is then ready for manufacture.

Manufacturing the first airplane is an expensive procedure since it requires the building of jigs and fixtures for the shaping up of the fuselage, wings, and other parts of the airplane. Where the number of airplanes of one type manufactured is limited, the cost of jigs and fixtures keep the cost of each airplane correspondingly high. Also, the manufacturer usually constructs a so-called "mock-up" of the airplane which consists

of a full scale model of the fuselage with the instrument boards, pilots' seats, controls, and so forth, in order that the manufacturer may be sure that the airplane is convenient to operate and that interference between the various parts of the airplane structure and controls may be eliminated.

In the manufacture, all materials used must meet the specifications of the Civil Aeronautics Authority and for this reason the airplane is continually inspected during the entire time of manufacture. After the airplane has been built, it is subject to the scrutiny of an engineering inspector who determines the safety and the practicability of the airplane as a whole. After being passed by the engineering inspector, the airplane must then be flight tested, and incidentally, the engine which is to be used in the airplane must be of a type and make also approved by the authority. Flight tests to determine the flying characteristics of the airplane are made, as well as drop tests to determine the rigidity of the under-carriage, and having passed all of these tests, the airplane receives an approved type certificate from the Civil Aeronautics Authority. It is then ready for market. It must be understood, however, that this approved type certificate, called an "A. T. C.", is valid only when the airplane is equipped with the particular engine mentioned in this certificate. Should the manufacturer desire to change the engine it would probably be necessary for him to make changes in the airplane structure and go through the same procedure as he did with the original airplane.

Even after the airplane has received its Approved Type Certificate and goes out into service, the regulations of the Civil Aeronautics Authority still control its destiny. The airplane must be flown by pilots approved to fly that particular type of airplane. It must be serviced and maintained by airplane and engine mechanics holding certificates of competency with respect to their ability to make the necessary inspections and to perform the necessary maintenance. In addition, it is subject to annual inspections by the Civil Aeronautics Authority inspector since its license to operate is good only for twelve months. Also, should the airplane be damaged in any way, repairs must be made in an approved manner and the repairs must be inspected by a Federal inspector.

In the air transport industry we find the Civil Aeronautics Authority regulations augmented by those of the Post Office Department. This is due to the fact that practically all of the airlines are engaged in carrying mail as well as passengers.

The operation of the huge air liners is regulated in every way. The airplane must be flown by pilots who have been properly certificated, not only to fly this particular type of airplane but also to be able to fly this airplane under conditions where the ground is not visible and instrument flying is necessary. The movement of the airplane along the airways must be made in accordance with certain specific rules regarding the position of the airplane on the airway, the altitude at which it is to be flown, and the periodic reports which must be made.

When the airplane is landed at the airport and the ground crew has taken over, the airplane must be inspected and engines and airplanes overhauled. Minute details concerning this overhaul and inspection must be entered in the airplane and airplane engine log books, and these log books are subject to inspection by the Federal inspector at any time at which he so desires.

All of these operations must be performed by personnel certificated by the Authority, and all materials and replacement parts must meet the original specifications of the manufacturer.

It would seem, perhaps, that all of these regulations would be a burden on the airlines, but on the contrary, the airlines not only gladly comply with the regulations but in practically every case investigated the airlines have added many more regulations of their own concerning inspection and maintenance of aircraft. The airlines have spared no expense in insuring the perfect performance of their airplanes and engines while in the air.

The radio, meteorology, and even bookkeeping and accounting sections are controlled by certain Federal regulations. Private flying is similarly regulated. It is evident, therefore, that the aircraft industry is regulated in a far greater degree than are other types of industry, and many changes have taken place since the days when the barnstorming pilot did all of the work of flying and maintaining his airplane. The industry has now become so complex as to require the services of hundreds of specialists, each of whom performs a special function in the

general operation of aircraft.

Employment in the transport industry might be divided into several groups:

It is the duty of the Executive Group to oversee the general welfare of its particular transport company. In this group are business men and lawyers, accountants, advertising men, clerks and even doctors, since all transport personnel must undergo annual, and in the case of the pilots, semi-annual, physical examinations.

Another group within the transport industry is called "Operations." It maintains and operates the airplanes. In this group are found the pilots, co-pilots, stewardesses, airplane mechanics, engine mechanics and stockroom men. Also included in this group is a Commissary Department whose duty it is to see that all supplies, such as newspapers and magazines, as well as all meals to be served aloft, are delivered to the airplanes at the proper time.

The Traffic Department, another group, is in direct contact with the public, giving out information concerning schedules and fares, making out reservations, and selling tickets.

The Department of Meteorology must forecast the weather, determine the velocity of the winds aloft, and in general furnish pilots with the information necessary for the successful completion of a particular run.

The Radio Section with its many specialists is required to keep in constant communication with all the airplanes in the

air, broadcasting continuous weather reports, transmitting and receiving necessary messages to and from the pilot.

The Dispatcher also has a responsible duty to perform since he must determine whether or not a flight is to be cancelled.

Within each of the groups mentioned above we find many specialists. This is particularly true of mechanics, since in the repair of airplanes men with various types of skill are required, and many different trades are included under the general classification of the Airplane Mechanic.

There are the following mechanical departments: propeller, sheet metal, welding, heat treating, radio installation and repair, and electrical installation, and in this connection it is interesting to note that some of the new transports have in them as much as from four to five miles of electric wiring. Other specialists are upholsterers, fabric workers, finishers who spray on the airplane the dope or enamel used for protective and decorative purposes, instrument repair men, riggers, and machinists. There is also the hydraulic department which takes care of brakes and shock struts, and at each terminal is a cleaning department which usually is the first rung of the ladder for the new employe.

In the engine mechanics branch there are also many specialists, including the overhaul men who overhaul the engines, and a number of specialists such as the carburetor, magneto, starter and generator repair men; and in order to see that these jobs

are properly performed there are the inspectors who inspect the engines and the airplanes, not only after overhaul and repair, but at the completion of each flight.

This rather short outline indicates the number of men required on the ground for each pilot in the air. It varies with the different airlines, but there are on the average from ten to twelve men on the ground for each airplane in the air.

In non-scheduled commercial flying, that is, the branch of flying not connected with the regular airlines, there are also many different types of jobs. As in the airlines, there are pilots, mechanics, and specialists, but in addition to this there are many others such as the airport superintendents with all their assistants, keeping the airport in condition and regulating flying about the airport; and traffic control operators who clear airplanes in and out of the airport very much in the same manner as trains are cleared in and out of a main railroad terminal. This is done by radio or by some form of visual signal, and it is necessary at any modern airport today to obtain clearance from the control tower operator before either taking off or landing.

Then there are the salesmen who sell flying courses, charter flights, airplanes, or other services which the aircraft industry has to offer. There are, also, a special group of insurance men who specialize in aviation insurance, aerial photographers, accountants, and many others doing the same type of work in the aircraft industry as would be found in other types

of industry, such as, for example, the automobile industry.

The largest employment group in the industry is the manufacturers, with many large factories located throughout the United States. These manufacturers may also be divided into several groups: manufacturers of airplanes, airplane engines, generators, magnetos, carburetors, starters, instruments, tires, brakes, shock struts, tubing, gasoline and oil, and many others.

The aircraft factories cover many different types of employment, from the fabrication of small metal fittings to the complete assembly and flight testing of airplanes.

It may be seen from the foregoing analysis that the aircraft industry is now a full-fledged business employing many thousands of skilled workers--truly a remarkable advance for an industry born within the present generation.

MILITARY VS. COMMERCIAL AIRCRAFT

Aircraft may be further subdivided into military and commercial aircraft. It is often assumed that commercial aircraft may, in time of war, be converted into military aircraft. This is not possible. In the first place, commercial airplanes are built with two factors in mind, safety and economy. Performance is desirable but it is never obtained at the sacrifice of safety. If commercial airplanes are to be operated at a profit they must be built so that they can be flown at a reasonably low cost. For this reason commercial airplanes are built with speeds considerably lower than those of military planes since the cost of speed is excessive both from the point of view of maintenance and

depreciation, and fuel supply.

The military airplane, on the other hand, is designed for high performance, and many desirable characteristics are subordinated in order that this high performance may be obtained. In the military service a slow airplane has, of course, very little value, while the airplane with the highest speed has a distinct advantage.

The life of military airplanes has advanced considerably since the World War. At that time the average life of the airplane at the front was approximately thirteen hours. This figure was low because of losses due to combat as well as the fact that airplanes wore out rapidly.

At the present time, under normal conditions, airplanes have a life of three thousand hours or more, depending upon the conditions surrounding their operation.

Service, or military, airplanes in the United States may be divided into three distinct groups: Army, Navy, and Coast Guard. In the first group, the Army, the number of different types of airplanes has increased considerably since the World War, due to the fact that the number of tactical assignments has increased and each assignment usually requires an airplane with particular qualifications.

Airplanes used by the Army Air Corps include the pursuit airplanes, usually single place, or in the later type, two place, with fixed machine guns firing through the propellers. These machine guns are synchronized with the propellers in such a way

that they do not shoot into the propeller as in the case of the early World War airplanes. At that time propellers were all made of wood and it was quite customary for a pilot to land with holes through the propeller blades. As a general rule holes made by these bullets were quite clean and there was a sufficient margin of safety so that the propeller did not break. However, with the synchronizing mechanism developed during the World War the machine gun cannot fire when the propeller blade is in front of the gun. The pursuit airplane is the fastest of the airplanes and is used for the protection of slower type aircraft, such as bombers.

A second type of airplane developed by the Army is the fighter, this being a radical departure from the conventional type of aircraft. It carries a crew of five, mounts six machine guns, and in addition carries a load of light bombs. The crew of the fighter consists of a pilot, a combination co-pilot and navigator, a combination radio operator and gunner, and two gunners located out-board on the wings. The flight ceiling of this type of airplane is approximately thirty thousand feet. This is a special type airplane designed for the special purpose of fighting off bombers.

A third type of Army aircraft is called the "Attack Airplane" or "Attack Bomber." These are of the single or twin engine type, usually two place, used for the purpöse of attacking troops, convoy trains, and other ground targets. A general in a staff car makes a very nice target. The largest of these attack bombers

carries six machine guns as well as a load of bombs, and since they must necessarily fly low and within the range of machine guns on the ground, they are usually equipped with armor plate on the under side.

A fourth type is the observation plane, a two or three place airplane equipped with the single engine. These are used for observation purposes, and although they are not expected to fight they are equipped with two or more machine guns. These airplanes are used for reconnaissance, photography, and artillery fire control.

There are also the bombers which may be divided into two classifications, the light and the heavy bomber. The heavy bombers run up as high as twenty-six tons gross weight, are equipped with four engines and carry bombs weighing up to two thousand pounds each. The radius of action of these airplanes is three thousand miles and they operate efficiently up as high as twenty-five thousand feet, carrying a crew of nine. These bombers bristle with machine guns, and when flying in formation at high altitudes are very difficult to stop.

The Army is also equipped with cargo airplanes which look more or less like our modern transports; and as their name indicates, they are used for carrying personnel, supplies of one kind or another, and in many cases, replacement engines. It is the practice of the Army, in case of forced landings due to engine failure, to fly new engines to the scene of the forced landing, take out the old engine, replace it with a new one and

then fly the old engine back to the repair depot for overhaul. This makes it unnecessary to fly mechanics, tools and equipment to the scene of a forced landing for the purpose of making repairs in the field.

The Army also has many training planes which, of course, have no value for defense purposes except in the training of pilots. These training planes are divided into two classes, namely, primary and advanced. A recent development in training planes consists of a combination primary and advanced type, where the primary type is converted to an advanced type by the reduction of the wing area, thus increasing not only the top speed but also the landing speed of the airplane.

This, in general, is a short resume of the various types of Army airplanes, each one of which requires a specialized type of pilot.

The Navy also has many different types of airplanes of one kind or another. It is interesting to note that in the development of naval aviation a large number of airplanes now used by the Navy are of the land type. This is due to the fact that Naval airplanes, particularly of the fighting type, must be fast; and land planes have the advantage over sea planes or flying boats in that the under carriages can be retracted, that is, folded up into the wings or fuselage, and in this way the parasite resistance decreased with a corresponding increase in top speed.

Also, many of these airplanes operate from aircraft

carriers which are essentially floating airports, and it is very much simpler to land and take off from the deck of a carrier in an airplane equipped with wheels than would be the case in an airplane equipped with pontoons or a hull.

The fastest of the Navy planes are called fighters. They are single seater, single engine airplanes of high speed, used mainly for the protection of bombers.

We also find the torpedo bomber and the scout bomber, both of these types usually being single engine land planes and housed on a carrier while at sea. As their name indicates, they are used for the purpose of launching torpedoes against surface craft. Then there are the larger bombers, called patrol bombers, equipped with two or four engines, in the form of flying boats or amphibians. These bombers carry a very large supply of gasoline and have a correspondingly large radius of action. We find, upon going into one of these bombers, that they are equipped with all the comforts of home: living accommodations for crew and mechanics, work shop, cook's galley with electric stoves, water distiller, dry ice refrigerator and a complete intercommunicating telephone system. We find an auxiliary engine supplying 110 volt electricity for operating wing flaps, anchor winch, general lighting, electrical controls, and the cooking equipment for the galley.

In addition to the above, the Navy is equipped with trainers very much of the same type as used by the Army except that they include flying boats, sea planes and amphibians.

The third service, the Coast Guard Aviation, does not have as many different types or as many airplanes as the Army or the Navy. It is only necessary to review the operations report of the Coast Guard Aviation, however, to see that they form a very important arm in the Coast Guard. I will quote from the report of the Coast Guard Aviation for the fiscal year of 1937:

> They flew a total of 780,545 miles and searched areas aggregating 5,862,618 square miles. They located 360 illicit distilleries which later were seized and destroyed. They identified 34,844 vessels at sea during the year; and they identified 6,444 airplanes. They located 37 smuggling vessels and two smuggling airplanes, and they seized nearly 42,000 gallons of contraband liquors valued at more than twenty thousand dollars. They reported 57 obstructions to navigation, flew out and dropped messages to 168 vessels not equipped with radio, warning them of impending hurricanes. They located 154 disabled ships, responded to a total of 506 requests for assistance. They flew out from their bases and rendered help to 293 persons, in many cases saving their lives. They took off from disabled vessels 11 persons who otherwise would have drowned. They took aboard a grand total of 948 persons in need of assistance in one form or another. They transported 185 medical cases, mostly from ships at sea where all other facilities were lacking for help of any kind. They rendered assistance to other government departments in 428 cases.

COMPONENT PARTS OF THE AIRPLANE

In the study of airplanes it is well to consider them on the basis of the major component parts into which all airplanes, irrespective of type or size, may be broken down. These are as follows:

Airfoils. Airfoils, or wings, are used for the purpose of obtaining the lift which supports the airplane in the air, and airplanes must at all times be flown in such a way that the lift on the airfoil is equal to the weight of the airplane. As will be shown later, this statement must be modified somewhat due to downloads on the horizontal stabilizing surfaces.

Contrary to popular belief, the lift on an airfoil during climb remains equal to the weight of the airplane, and we find that climb is due to the vertical component of the propeller thrust which moves the airplane along an upward inclined path. Were it not for this propeller thrust, kinetic energy stored up in the airplane during a dive, or rising currents of air, climb would not be possible.

Fuselages. Fuselages in airplanes are used for the purpose of housing passengers, cargo and crew as well as providing a place for the attachment of the rear control surfaces. Usually, though not always, the engine is mounted in the fuselage. The fuselage produces the major portion of the drag forces which retard the airplane and it must therefore be carefully designed if the speed of the airplane is to be satisfactory without a considerable expenditure of power.

Undercarriages. The undercarriage may be considered as an

attachment to the fuselage which is used for the purpose of supporting the airplane while on the ground. It contributes nothing to the lift or forward motion of the airplane: on the contrary, it retards this forward motion even in the case of undercarriages which may be fully retracted into the airplane or wings.

Engines. The airplane engine furnishes the power which sustains the airplane in the air, and we find that airplane engines are built in a multiplicity of shapes and sizes, and the choice of the type airplane engine to be used is dependent upon the particular airplane in which it is to be used, but we find that all of these engines have exactly the same operating principles and that the difference lies merely in mechanical arrangement.

No discussion of the Diesel oil engine will be included in this paper since at the present time the Diesel oil engine, due to its excessive weight and high cost of maintenance, cannot economically be used in modern airplanes.

Propellers. The propeller, which is connected directly to the engine either by attachment to the crank shaft or in some cases through reduction gears for reducing propeller speed, is used for converting the torque developed by the engine into the thrust necessary for propulsion. We find the all-metal propeller rapidly replacing wooden propellers in all installations except in the case of small engines.

Instruments. Airplane and engine instruments are used for the purpose of indicating to the pilot the altitude of the air-

plane and the operating condition of the engine. They report to him not only present conditions but in many cases warn him of trends which, if continued, might become serious.

Navigational instruments assist in the navigation of the airplane particularly at times when the ground is obscured.

The instrument board of the modern airplane displays an awe inspiring array of instruments and controls, all of which have been made necessary by the technological advancement of the art of flying.

AIRFOILS

Theory of Flight

For many years it was recognized that moving air exerted forces against stationary bodies. This principle was first used in the propulsion of boats by sails, and although these boats were skillfully sailed, the laws governing the forces acting were not clearly understood. The principle of air pressure against flat surfaces was also used in the case of the kite where the forces acting upon the kite result in an upward lift equal to the weight of the kite, plus the kite string, thus keeping it in the air.

This same principle was then applied to an airplane and it was assumed that the forces produced by the propulsion of the airplane through the air would result in vertical lift of sufficient magnitude to equal the weight of the airplane. It was found that the speed necessary in order to maintain flight was fairly high and somewhat proportional to the weight of the airplane.

A number of early airplanes were built with plane surfaces, inclined slightly to the horizontal, but as was to be expected, some designers shaped these surfaces to simulate a bird's wing. It did not take very long to discover that wings, or airfoils, having the same general curvature as a bird's wing were much more efficient with respect to lift than were the flat wings. Investigation of the improved characteristics of the curved, or

"cambered," wing was then undertaken and it was discovered that the lift on the airfoil was due not only to the direct pressure of the air on the under surface, but also to a partial vacuum over the upper surface, thus making the pressure much more effective. This increased lift on the airfoil was due to the effect observed by Bernoulli, namely, that the pressure in any fluid stream is least where the stream velocity is greatest and greatest where the velocity is least. This may be expressed mathematically by the equation

$$\frac{1}{2}\rho V^2 + P + \rho gh = K$$

where ρ = density of the fluid, V = velocity at any point, P = the pressure in the fluid at the same point, ρgh = potential energy due to position and K = a constant.

It will be noted from this equation that an increase in fluid velocity must result in a decrease in the pressure at the same point if the sum of all the terms of the equation is to remain constant.

Analysis of airflow over a cambered wing shows that the vacuum on the upper surface is due to the fact that the camber increases air velocity over the upper surface, resulting in a decrease in the air pressure, and since the initial air pressure is one atmosphere, this decrease in pressure results in a partial vacuum. Measurement shows that in normal flight the lift, due to this partial vacuum, represents approximately two-thirds of the total lift on the airfoil, and it may be seen from this that the curvature of the wing is of utmost importance. Figure 1

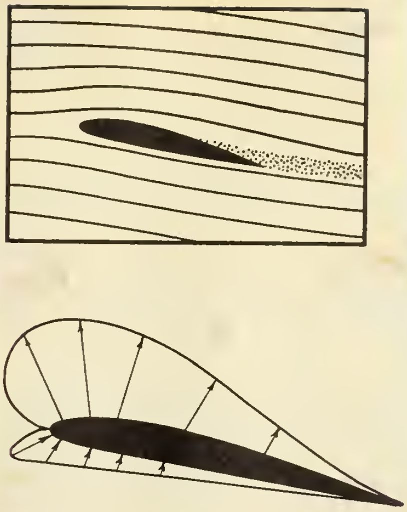


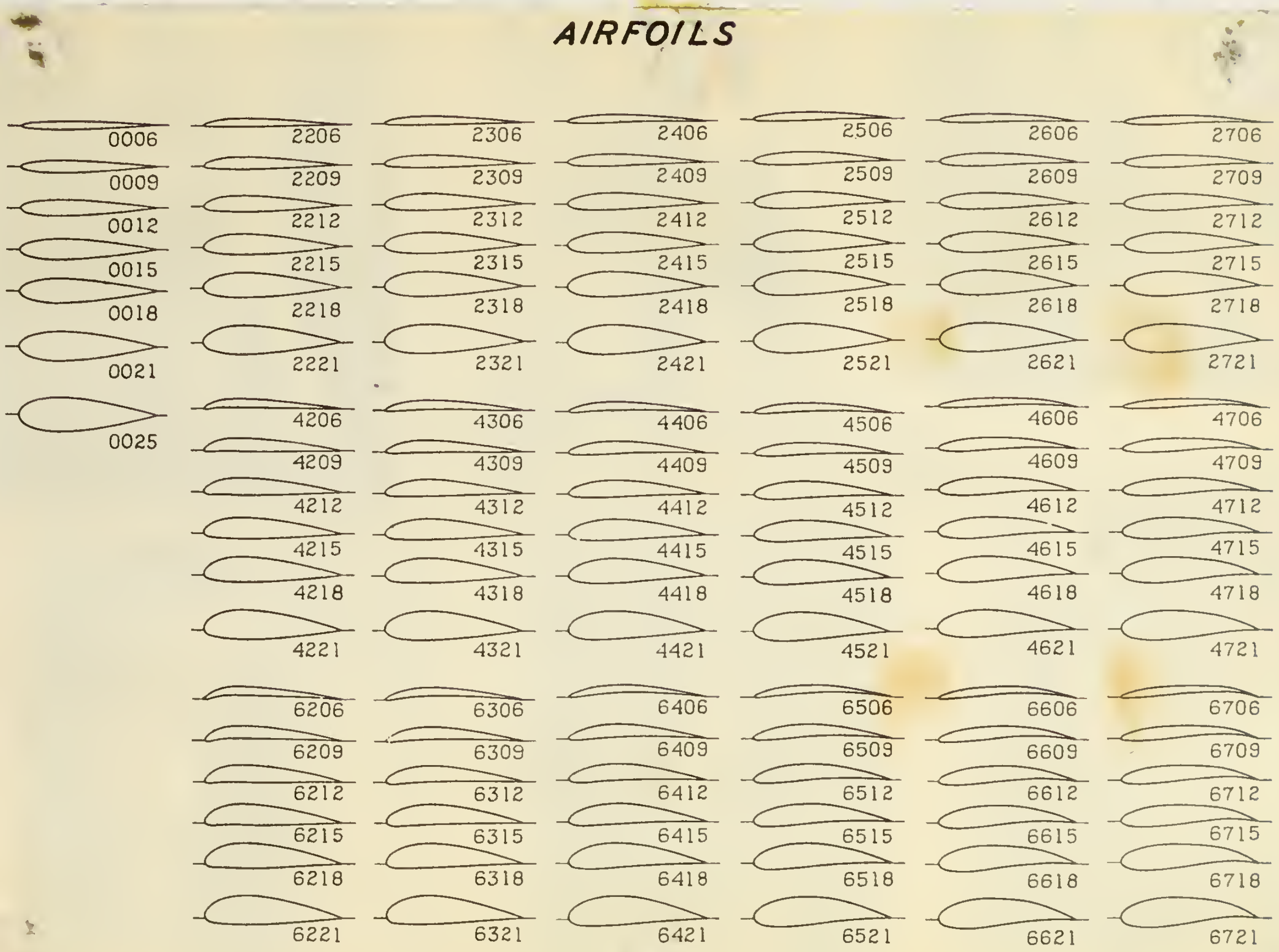
Figure 1

Pressure on an airfoil

illustrates the forces on such an airfoil.

From the above discussion it is evident that an increase in the camber, that is, a thickening of the wing, will result in an increase of the air velocity over the upper surface, and we find that thick wing sections are commonly referred to as "high lift" airfoil sections.

Since an increase in the thickness of the wing results in an increased air resistance, or "drag," it has been found that for high speed, thin wing sections, although less efficient from a lifting standpoint, are more desirable since the drag forces increase very rapidly at high speeds, and for this reason, drag becomes the predominant factor in the choice of an airfoil section.



N.A.C.A. airfoil profiles

Figure 2

Figure 2 shows a number of airfoil sections which have been tested by the N. A. C. A. and illustrates the large variety of types from which the airplane designer may choose.

In a scientifically designed airplane, the performance characteristics of the airplane must be determined in advance, and in this respect airplane design does not differ from the design of many types of automotive devices, such as, for instance, a steamship. It is necessary here to obtain accurate information concerning weight, load carrying capacity, maximum speed, draft, fuel consumption, and many other items. This must also be true in the case of the airplane, and for this reason it is necessary that certain wind tunnel tests be made on scale models in order that these characteristics may be predetermined.

One of the many important items, that of the lift on the airplane wings, may be determined by testing in a wind-tunnel accurate scale models of the wings which are to be used in the completed airplane. In these tests the model wing is suspended in the tunnel and air is blown at constant velocity past this wing and at the same time the lift and drag of the airfoil at various angles of attack are determined. This information is then plotted, and curves such as shown in Figure 3 are obtained. These results are directly applicable only at the particular air speed used, and the airfoil section tested. This data must therefore be corrected for full-scale effects as well as the higher speed at which the airplane will operate.

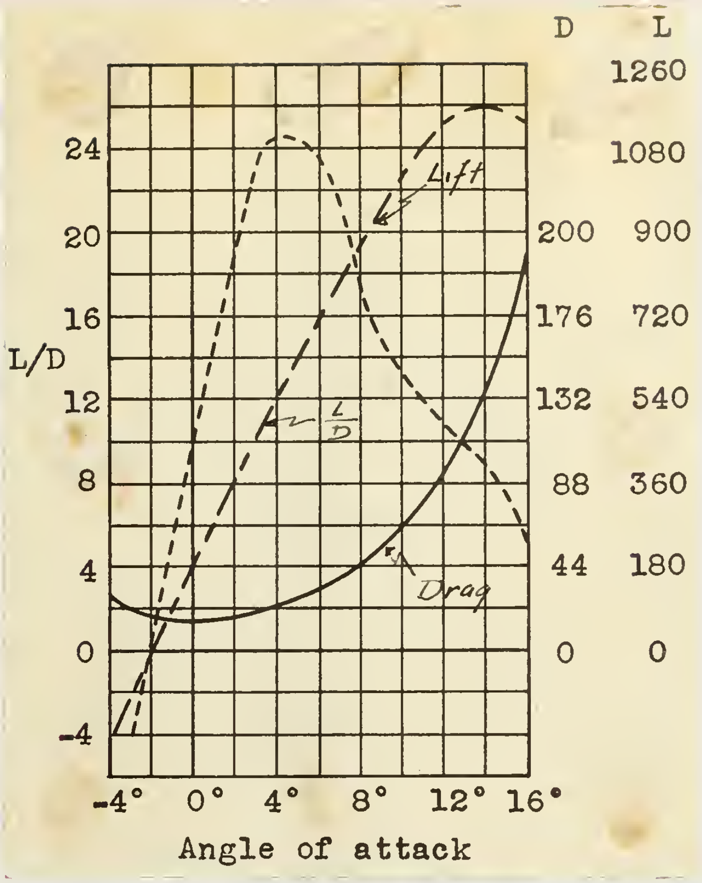


Figure 3

Lift and Drag Curve

Knowledge is therefore necessary concerning the variation of lift and drag with velocity, and in analyzing this lift in conjunction with Bernoulli's principle we find that it is proportional to the air density, the wing area, angle of attack, and the square of the velocity. The mathematical equation is:

$$\underline{L = L_c AV^2}$$

A = area
V = velocity
L_c = lift coefficient

L_c is proportional to the angle of attack which is defined as the acute angle between the wing chord and the relative wind.

It must be noted that the above formula does not contain the air density. This, however, is corrected by reducing the lift measured in the wind tunnel to standard atmospheric conditions. In this way, L_c, when determined, accounts for air density. Drag is also proportional to these same factors.

In preparing information for use in full-scale models, the lift is reduced to a unit basis, namely, the lift per square foot of wing at one mile per hour under conditions of standard barometric pressure and temperature, and a series of these unit lifts is determined for various angles of attack.

Let us assume that it is desired to find the lift on a full scale airfoil having the same airfoil shape as that which produced the curves given in Figure 3. The data on the full size airfoil is as follows: Type airfoil, N. A. C. A. #4412, having an area of 120 sq. ft., with a probable top speed of 200 m. p. h. at an angle of attack of 4°. Let us assume that this airfoil is similar to that shown in Figure 2. A small model airfoil 36" long by 6" wide, having the same airfoil section is tested in the wind tunnel at an air velocity of 40 m. p. h. The results of this test are obtained from Chatfield, Taylor and Ober, "The Airplane," Fourth edition, P. 19, and are listed in Table I.

Since the angle of attack has been assumed to be 4°, reference to the following table will indicate that at this angle the model airfoil had a lift of 4.263 pounds.

Table I. Results of Test of Model Airfoil, 36 by 6 in. Air speed, 40 m. p. h.

Angle of attack, degrees	Lift, pounds	Drag, pounds
-6	-0.231	0.115
-4	0.654	0.091
-2	1.550	0.096
0	2.495	0.119
2	3.364	0.168
4	4.263	0.236
6	5.115	0.319
8	5.930	0.412
10	6.635	0.522
12	7.263	0.635
14	7.624	0.779
16	7.217	1.029

This lift reduced to one square foot at one mile per hour becomes

$$L_c = \frac{4.263}{1.5 \times 1600} = .00178$$

L_c is the "lift coefficient" and is the lift on one square foot of wing at one mile per hour, assuming standard barometric pressure and temperature. This lift coefficient is then used in the formula

$$L = L_c AV^2 \text{ (standard air)}$$

and for our particular wing

$$L = .00178 \times 120 \times 200^2 = 8550 \text{ lbs.} \quad \text{(total lift)}$$

It may be seen, therefore, that an airfoil of this shape traveling at 200 m. p. h. and having an angle of attack of 4°, will be capable of sustaining in flight an airplane weighing 8550 pounds, which must necessarily include the weight of the wing itself.

This value of total lift should now be modified somewhat by the application of certain correction factors which take into account the scale effect, plan form and the arrangement of the wings on the airplane. These correction factors, although relatively small, cannot be disregarded in careful design, and may be obtained from curves which are readily available in any one of the many aeronautical publications dealing with this subject.

It may be seen from Figure 3 that an increase in angle of attack of the airfoil will result in an increased lift, and it is by this means that the pilot is enabled to decelerate the airplane and still maintain a lift equal to the weight of the airplane.

The process of landing an airplane, therefore, consists of closing the throttle when approaching an airport, and as the speed of the airplane decreases, the accompanying decrease in lift is compensated for by an increase in the angle of attack. This process may continue only up to a certain point, since it can be seen in Figure 3 that an increase in the angle of attack

beyond 14° will result in a decrease in lift, and that beyond 16° this lift decreases very rapidly, resulting in a complete loss of control of the airplane by the pilot.

The rapid decrease in lift beyond 14° is due to the fact that at this angle the vacuum on the upper surface of the wing becomes so great that the inertia of the moving air is no longer sufficient to maintain a smooth flow, and turbulent flow results causing a marked decrease in the lift. This angle of attack, namely, 14°, which is approximately the same for all airfoil sections, is called the stalling angle, or the maximum angle of attack, and in learning to fly a student pilot is continually warned that he must keep the nose of the airplane down in order that loss of control due to stall may be prevented.

It is often stated that a three point landing is the best kind of a landing. This is due to the fact that in the design of airplanes, the length of the undercarriage and tail wheel, as well as the setting of the airfoil with respect to the fuselage, are such that when the wheels of the airplane and the tail wheel contact the ground simultaneously, the airfoil is at an angle of attack of 14°.

Having determined the total weight of the airplane which may be sustained by the airfoil just discussed, let us proceed to determine the horse power required to maintain the desired speed. In order to do this we must consult Table I, and we find that at this same 4° angle of attack the airfoil has a drag of 0.236 pounds. In a method similar to that by which we determined

the lift coefficient, the drag coefficient is determined, and we find that the drag coefficient is

$$D_c = \frac{D}{AV^2} \quad \text{(standard air)}$$

Therefore $$D_c = \frac{0.236}{1.5 \times 1600} = .0000983 \text{ lbs.}$$

D_c is commonly called the "drag coefficient" and is the drag which must be overcome, per square foot of wing at one mile per hour, and at an angle of attack of 4^o.

We find, therefore, that the total drag may be determined as follows:

$$D_c \, AV^2 = .0000983 \times 120 \times 40{,}000 = 472 \text{ lbs.}$$

which means that the propeller thrust to maintain unaccelerated flight must be equal to 472 lbs, and the propeller horsepower must be

$$\frac{472 \times 2000 \times 5280}{60 \times 33000} = 252 \text{ h. p.}$$

Since the average propeller efficiency at this speed is 80%, we find that the engine horsepower will be

$$\frac{252}{80} = 315 \text{ h. p.}$$

and, as in the case of total lift, the above computations must be modified somewhat by similar correction factors. To this horsepower must be added power required to force the fuselage through the air.

In this simple manner, the engineer determines the horse-

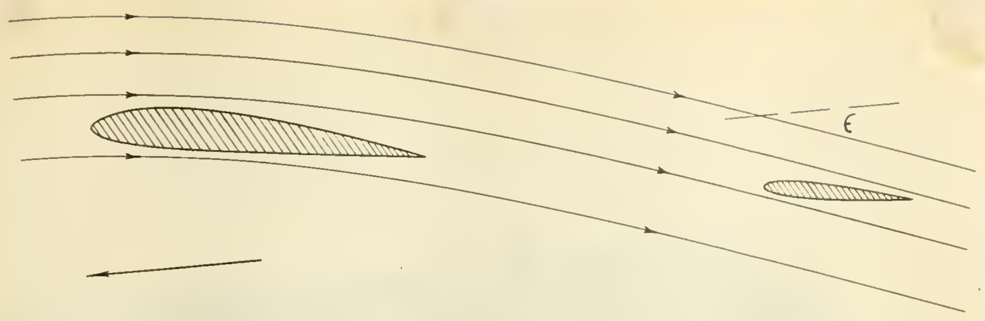
power required for a certain speed; or having selected the horsepower, he may determine the maximum speed of his airplane. It will, of course, also be necessary for him to test the fuselage in the wind tunnel in order to obtain the drag curve of this part of the airplane. The combination of the two will then give him the required horsepower or the top speed, assuming a selected horsepower.

It has been found, in wind tunnel testing, that very often a fuselage airfoil combination tested together will give a resultant total drag less than the sum of the drag of the airfoil plus that of the fuselage; and at the present time it is common practice to test a complete airplane model rather than its sections. Models of all of the large transoceanic airplanes are wind tunnel tested for many months before actual construction begins.

Stability in Flight

If an airfoil is placed in the wind at a positive angle of attack, then the air lifting the wing is deflected downward as shown in Figure 4. This downward turning of the wind is known as "downwash."

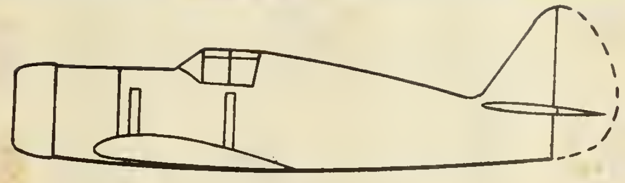
It would probably not be apparent from a casual inspection of a conventional airplane such as shown in Figure 5 that the horizontal tail surfaces carry a down-load in ordinary flight, for they appear to be set at approximately the same angle to the horizontal axis of the airplane as are the wings. The



Effect of downwash on the horizontal tail surfaces

Figure 4

wings, however, are working in undisturbed air while the tail surfaces are operating in air which has previously passed over the wings, as shown above.



Side view, conventional airplane

Figure 5

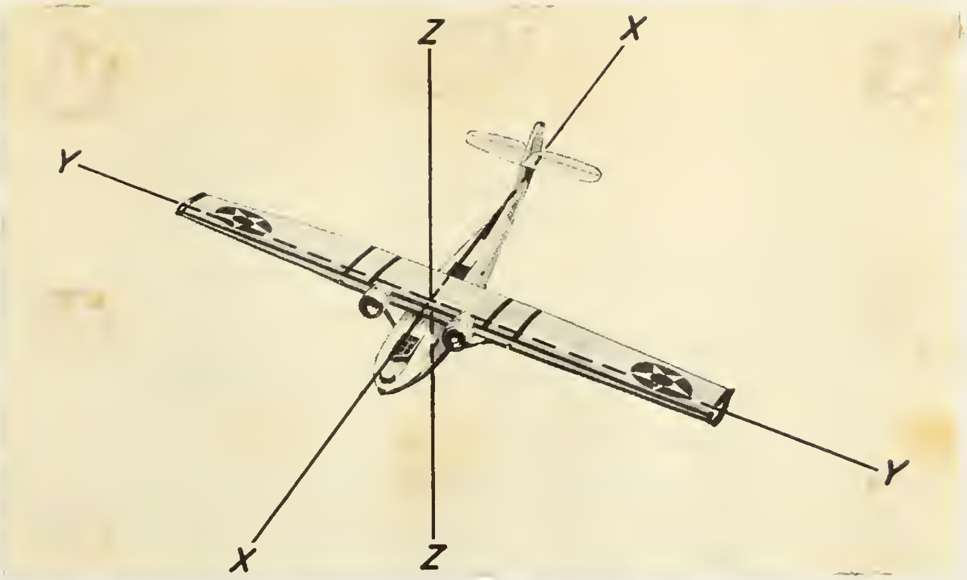
In view of the phenomenon of downwash, it is apparent in Figure 4 that the air which strikes the tail surfaces has a considerable downwash angle with respect to the longitudinal axis of the airplane. The horizontal tail surfaces, therefore, are really acting at a negative angle of attack with reference to the direction of the air which strikes them, and they are for

this reason exerting a downward rather than an upward force upon the airplane.

Since an airplane in flight is a free body, that is, one that is not restrained by a track, held down by gravity on a flat surface or supported on fixed bearings, it will always rotate about its center of gravity. The three mutually perpendicular axes about which angular motion can take place then intersect at the center of gravity and these axes are also in the directions of the three components of the airplane's linear motion.

The attitude of the airplane is referred to these three primary axes which are: the longitudinal axis, in the plane of symmetry, usually parallel to the propeller shaft; the vertical axis in the plane of symmetry perpendicular to the longitudinal axis; and the lateral axis perpendicular to the plane of the other two. They are usually designated as the X, Y, and Z axes respectively, as shown in Figure 6. The rotations about these axes are called roll, pitch, and yaw respectively.

Dynamic balance of an aircraft is also described relative to these three axes. When an aircraft has longitudinal balance it is in fore and aft equilibrium and does not have a tendency to pitch. Lateral balance is indicated by no tendency to roll. The third state of equilibrium is called directional balance, and it is identified by no tendency of the aircraft to yaw.



Three axes of an airplane

Figure 6

LONGITUDINAL STABILITY. An airplane is said to possess longitudinal stability when it has a tendency to keep a constant angle of attack with reference to the relative wind, that is, when it does not tend to put its nose down and dive or to lift its nose and stall. Longitudinal stability therefore refers to motion in pitch. In simple longitudinal motion the center of gravity of the airplane moves in a vertical plane.

The angle of attack at which the airplane is in equilibrium and at which it tends to maintain level flight if longitudinally stable is called the angle of balance. Since there is a definite airplane speed corresponding to each angle of attack, the speed corresponding to the angle at which the airplane balances is called the "trimming speed."

When the resultant lift on the airfoil is acting through the center of gravity, no stabilizing tail surfaces are needed.

This condition is represented in Figure 7 in which the airplane is also represented as a lever for the purpose of simplifying the explanation of horizontal stability. If this airplane continues in normal flight, there will be no tendency toward pitch.

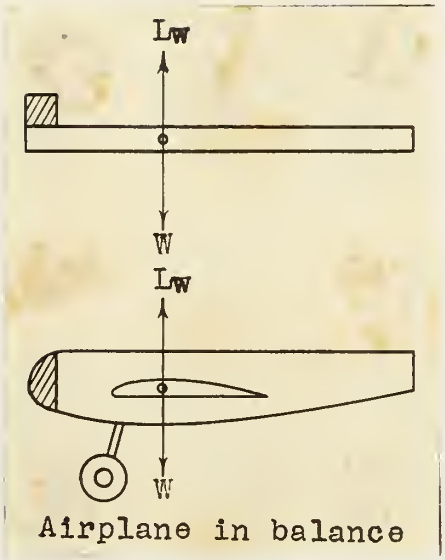
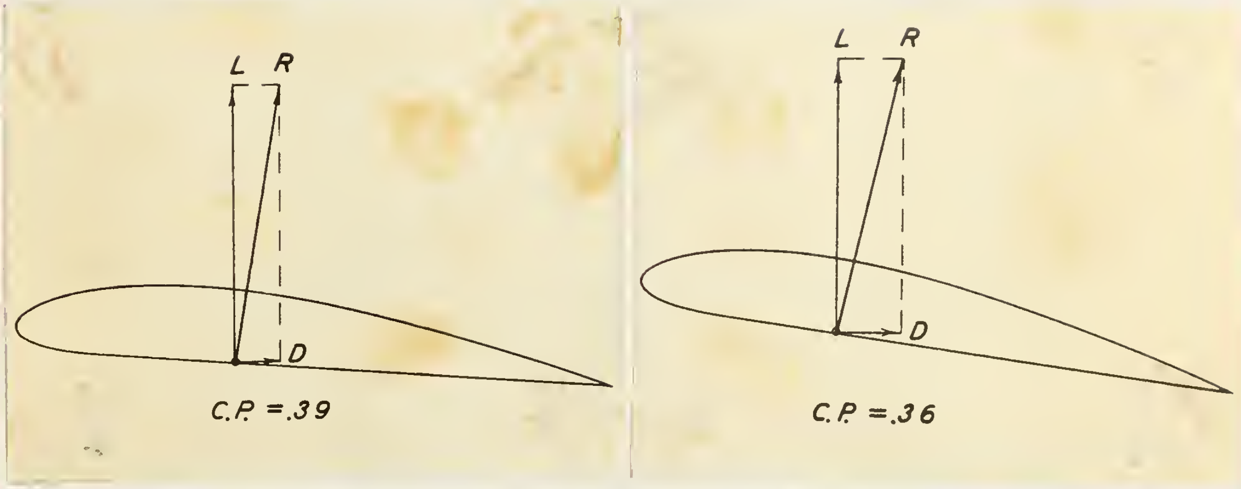


Figure 7

Before proceeding, however, we must consider the changes in the position of the resultant lift on an airfoil at various angles of attack. The increase in lift with an increase in angle of attack up to the stalling angle has already been discussed.

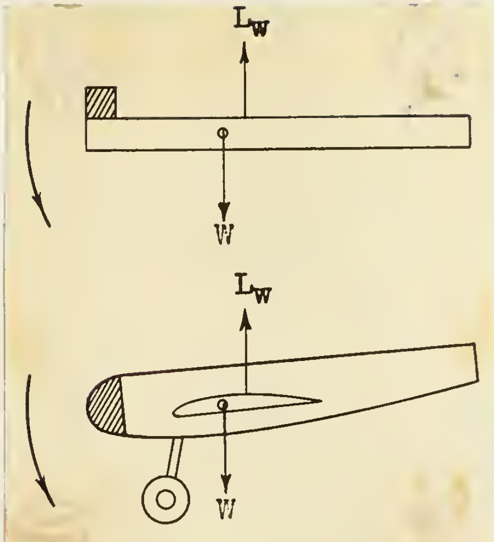
An investigation of the movement of the center of lift on an airfoil reveals the fact that at the usual normal angle of attack, the center of lift is located approximately one-third of the distance from the leading to the trailing edge. An increase in the angle of attack will cause this center of lift to move

forward due to the increase in vacuum near the leading edge of the wing. Conversely, a decrease in angle of attack will result in a rearward motion of the center of lift. This is illustrated in Figure 8.



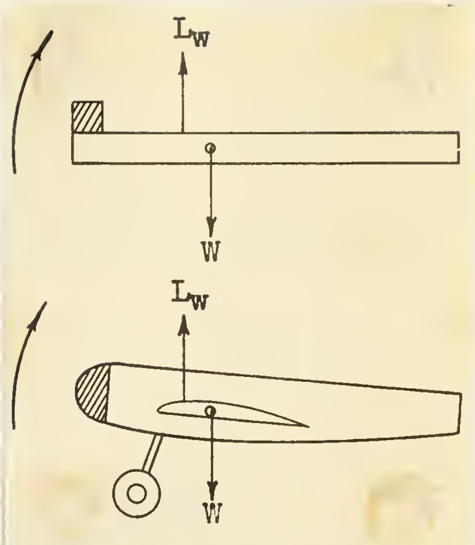
Center of pressure movement with changing angle of attack
Figure 8

In view of the above movement of the center of pressure, we find that should the nose of the airplane in Figure 7 drop, the center of lift would move toward the rear, and in this way produce a couple which would cause counter clockwise rotation, thus forcing the nose of the airplane still further down. Conversely, should the nose of the airplane be moved up slightly, the forward motion of the center of lift would then produce a clockwise moment tending to pull the nose still further up, a condition which would result in a stall. These conditions of instability are shown in Figures 9 and 10.



Airplane in dive

Figure 9



Airplane in climb

Figure 10

It is then evident that an airplane equipped with a single airfoil would be unstable in pitch since a displacement of the wing (change in angle of attack) produces unstable characteristics. A tail surface is therefore necessary on the usual airplane to overcome the instability of the wing.

The action of the tail surfaces may be explained by referring to Figures 11, 12 and 13.

Figure 11 shows an airplane in level flight. The weight of the airplane is indicated by the arrow marked (w) acting at the center of gravity. The lift of the wings is acting at the center of lift and is designated by the arrow (L_W). The third important force is the downward "lift" on the horizontal tail surface, and this is indicated by the arrow marked (L_t).

Since the center of lift is behind the center of gravity, it is evident that were it not for the force on the tail, the

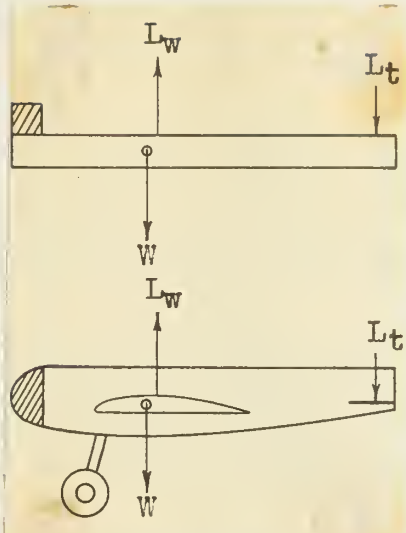


Figure 11

Airplane in balance,
nonlifting stabilizer

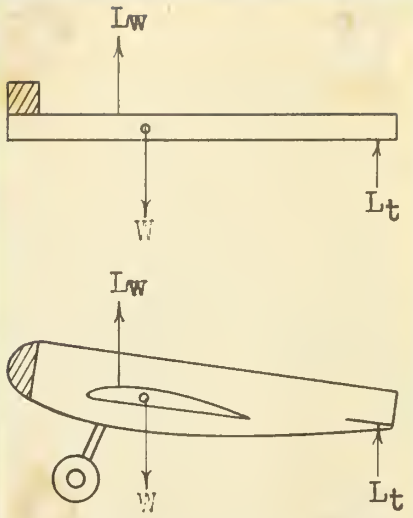


Figure 12

Airplane in climb,
nonlifting stabilizer

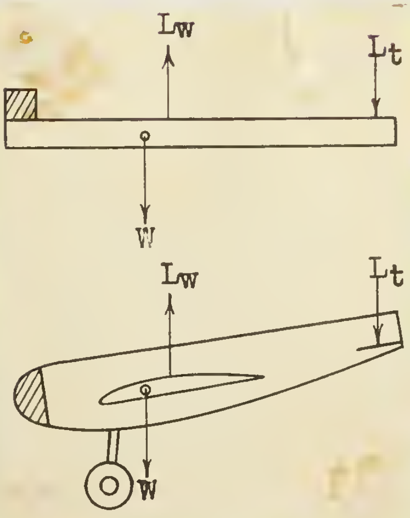


Figure 13

Airplane in dive,
nonlifting stabilizer

airplane would dive. The function of the horizontal tail surfaces at ordinary angles of attack is to supply a down load sufficient to counteract this diving tendency. The airplane therefore balances in the same way in which a lever can be made to balance under the influence of three unequal forces. The lifting force on the lever corresponds to the lift on the airplane and the point of support corresponds to the center of gravity. The large downward force corresponds to the weight of the airplane. The small downward force, L_t, corresponds to the down load on the tail surfaces and the point at which it acts corresponds to the center of lift of the tail surfaces. It is evident, also, that the lift must be equal to the sum of the weight and the down load on the tail, but since the tail force is usually small, the lift on the wing is nearly equal to the weight of the airplane.

In Figure 12 the airplane is in a climbing position. Now we find that the down load on the tail has reversed and it has become an up load to balance the center of pressure travel of the wing, which has now moved forward past the center of gravity. The tail is lifting because it is at a positive angle of attack when in this position. This reversal of the lifting force on the tail surfaces therefore compensates for the forward movement of the center of pressure, and in this manner counteracts the tendency for the airplane to go automatically into a stall position.

Figure 13 demonstrates the increase of the down load on the

tail surfaces when the airplane is in a dive. Again this is necessary for equilibrium, and the increase in the down load is due to the increase in negative angle of attack of the tail surface. This type of tail surface is called a "non lifting stabilizer."

Figures 14, 15, and 16 deal with an airplane using a lifting stabilizing tail surface. In this case the wings are placed on the airplane in such a way that the center of lift is always forward of the center of gravity regardless of the flight attitude of the airplane.

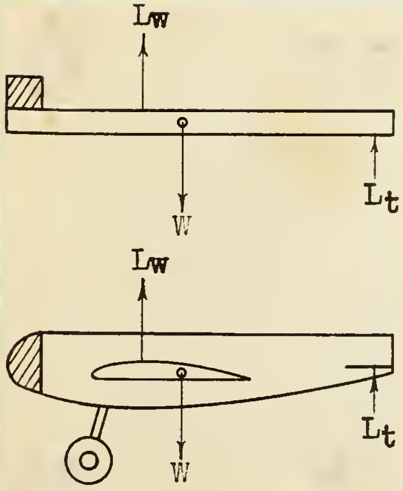


Figure14

Airplane in balance,
lifting stabilizer

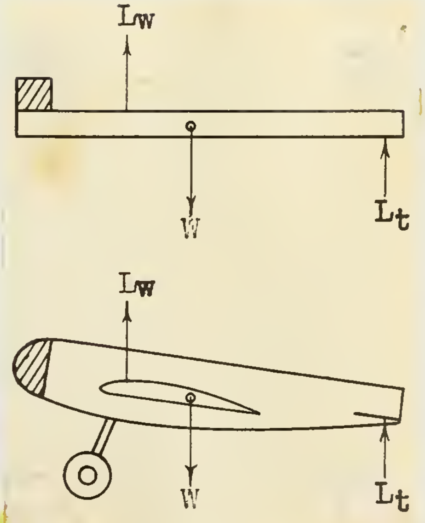


Figure15

Airplane in climb,
lifting stabilizer

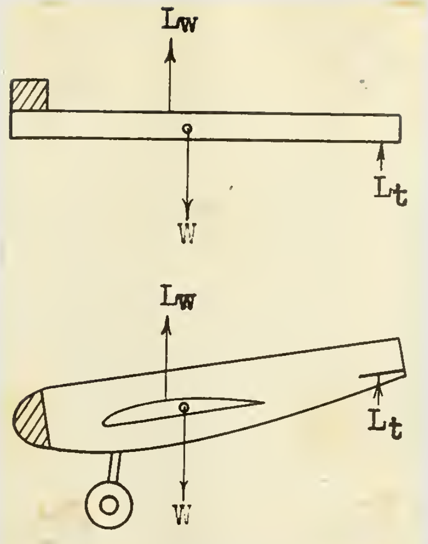


Figure 16

Airplane in dive,
lifting stabilizer

Up to this point, in the six cases presented, no mention of downwash or its effects has been made. Downwash varies with change of angle of attack, and as the lift of the wing increases, the amount of downwash increases. This downwash is the actual angle through which the air is turned at the tail surfaces by the influence of parts of the airplane other than the tail itself. It is evident, for example, that if an airplane has a symmetrical tail section set at an apparent angle of attack of three degrees, with a true downwash angle also equal to three degrees, that the resulting angle of attack will be 0°. If, on the other hand, the original apparent angle had been five degrees and the downwash three degrees, the true angle would be plus two degrees, and the tail would have a positive lift.

Thus, in our examples using a non-lifting stabilizer, the tail surfaces were set at a certain angle of attack which, when the effects of downwash are calculated, will shift the lift of the tail around from positive to negative, as the case may be, to maintain equilibrium.

In the "lifting stabilizer", however, no such reversal of lift takes place and it will be noted in Figure 15 that the lifting stabilizer in climb has its positive lift increased, thus tending to maintain equilibrium. In a dive the force on the lifting stabilizer is decreased in order that this same equilibrium may be maintained.

Assuming the plane to be trimmed at 150 m. p. h. with no force on the elevator control surfaces, then should some of the passengers move to the back of the cabin, the center of gravity would also move toward the rear. To fly at the same speed an additional upward force on the stabilizer would be required, and it would be necessary for the pilot to move the horizontal control surface or elevators down in order that this upward force might be provided. This condition would therefore necessitate continuous pressure on the controls by the pilot, resulting in considerable fatigue. To eliminate this necessity, airplanes are provided with adjustable horizontal stabilizers and rather than increase the tail force by the use of the elevator control, the pilot may change the angle of attack of the stabilizer to compensate for this change in the position of the center of gravity. Similarly, should the center of gravity move forward

for any reason, an opposite movement of the stabilizer will compensate for this change, and in this way the pilot is relieved of the necessity for continuous application of power to the elevator controls. An adjustable stabilizer is shown in Figure 17.

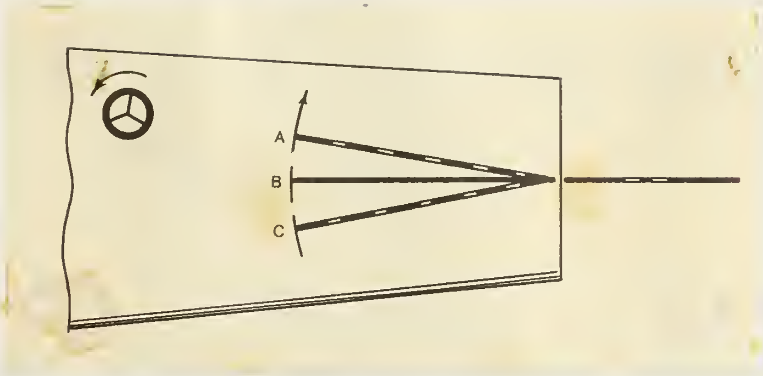


Figure 17
Adjustable stabilizer

LATERAL STABILITY. Lateral stability is a little more difficult to describe due to the interaction of the two rotations concerned--those of roll and yaw. Figure 18 illustrates one phase of lateral stability. It is not possible to speak separately of the rolling and yawing motions since one involves the other. A yawing motion produces a rolling motion, and a rolling motion causes a yawing motion.

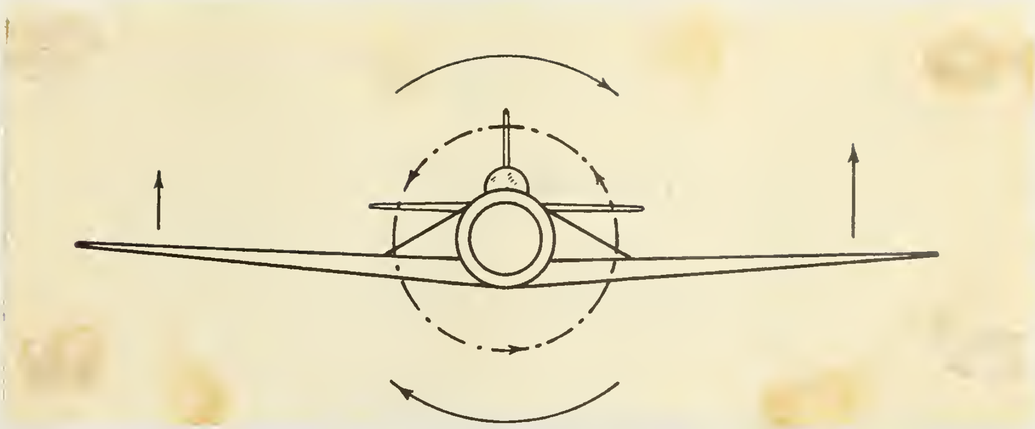


Figure 18

Effect of torque

A side slip tends to produce both roll and yaw, and the yaw should be such as to turn the airplane into the direction in which it is slipping.

Lateral balance is secured by placing the center of lift in the plane of symmetry containing the center of gravity. Lack of lateral balance is indicated by a tendency for one wing to droop, thus causing rolling.

This drooping tendency is due primarily to the torque of the engine since this torque produces a tendency for the airplane to roll in a direction opposite to that in which the engine is turning.

Practically all American aircraft engines rotate in a clockwise direction as viewed from the pilot's cockpit, and we find therefore that engine torque tends to cause the airplane to roll in a counter clockwise direction.

To offset this tendency, it is necessary to increase the lift on the left wing and decrease the lift on the right wing, in order that a compensating rolling motion may be produced. In order that the symmetry of the airplane may not be destroyed, this increase of lift on the left wing is obtained by warping down the trailing edge of the wing near its tip, and in this manner increasing its effective angle of attack.

Similarly, the trailing edge at the tip of the right wing is warped upward, decreasing its effective angle of attack and therefore also its lift. The warping down of the trailing edge is generally called "wash in," while the upward warping of the wing is called "washout."

Since the rolling moment produced by engine torque varies with the horsepower output, we find that this compensating moment must vary with the throttle setting, and fortunately this is wholly automatic since, should the throttle be closed slightly, thus decreasing torque, the decreased airplane speed also results in a decrease of the compensating rolling moment.

DIRECTIONAL STABILITY. Stability about the vertical axis is generally designated as "directional stability," since it is a measure of the tendency of an airplane to continue flight in a straight line. From the lift and drag curves discussed earlier, we find that wash-in and wash-out necessitated by engine torque result in an increased drag on the left wing due to its increased angle of attack. Similarly, wash-out reduces the drag on the right wing due to its decreased angle of attack.

We find, therefore, that changes in rigging to produce lateral stability produce a tendency for the airplane to swing continuously toward the left. The difference in drag forces on the left and right wings are indicated by the arrows in Figure 19.

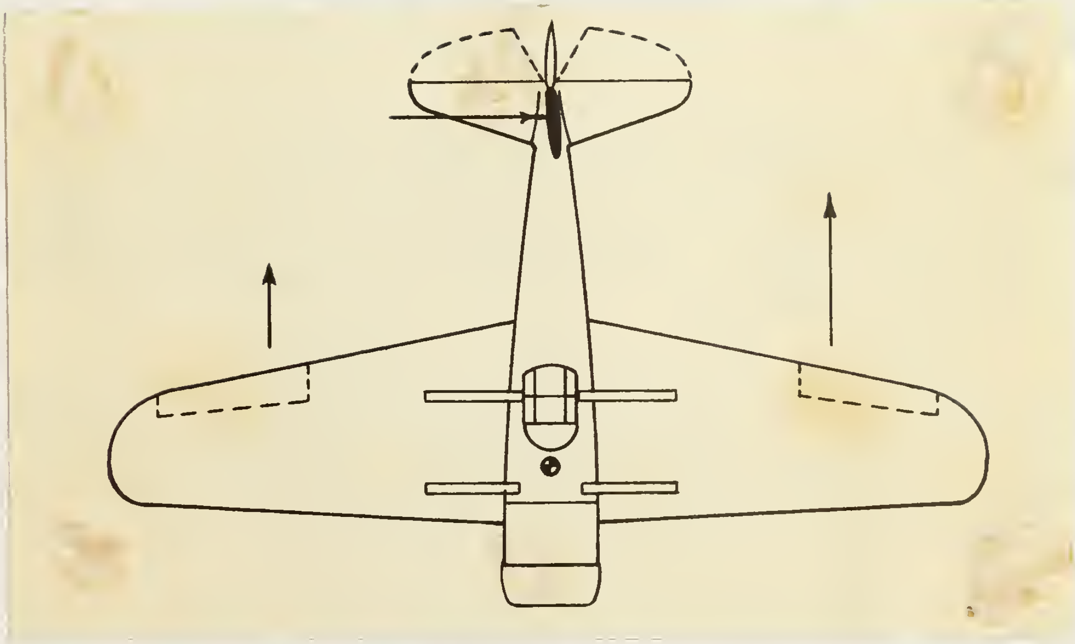


Figure 19

Effect of wash-in on drag

To compensate for this turning tendency, the airplane is provided with the fixed vertical tail surface called the "vertical fin", which is slightly offset from the longitudinal axis of the airplane in such a way that a horizontal lifting force indicated by an arrow is produced. This force on the vertical stabilizer may be varied by changing the angle of offset until the turning moment produced counterbalances the turning moment due to the difference in drag.

In this manner, we have an airplane which is stable about all three axes, and one which under normal flight conditions will continue in a straight and level course without the use of controls manually operated by the pilot.

Details of Construction

Airplane wings may be divided into two classes with respect to their material and construction, namely, wood and metal.

Within the past ten years the use of metal has increased rapidly for certain types of airplanes. Metal construction, however, is very much more expensive, and we find its use limited to comparatively large airplanes. Wood is still used to a great extent in the small, privately owned airplanes, and many years will probably elapse before wood construction is entirely superseded by metal construction. This is due to the fact that wood construction simplifies repair in case of breakage, since it is possible to repair or replace broken members very quickly, whereas in the case of metal wings it is necessary to replace completely the damaged part, which usually can be done only by complete disassembly of the entire wing. In the case of the privately owned airplane the cost of repairs is a predominant factor, and for this reason, we find that the wings of approximately eighty percent of all privately owned airplanes are constructed of wood.

In wooden construction we find that spruce is almost universally used since spruce has a higher strength weight ratio

than any other type of material. Strength weight ratio is determined by dividing tensile strength in pounds per square inch by density in pounds per cubic foot.

Table II. Strength Weight Ratio Table

MATERIAL	Density Lbs. per cu. ft.	Tensile Strength Lbs. per sq. in.	Strength Weight Ratio
Spruce	27	10,000	370
Ash	41	14,500	353
Duraluminum	175	55,000	314
Mild Steel	480	55,000	115
Chromemolybdenum Steel	480	95,000	198

Table II lists the density, tensile strength, and strength weight ratio of five materials commonly used in aircraft construction. It will be noted that spruce compares very favorably with all of the other materials, and it is for this reason that it has been so extensively used in aircraft construction. It must be recognized, however, that these figures do not tell the entire story. Wood is a nonhomogeneous material and for this reason it is not possible to compute to a nicety the exact dimensions required to resist certain stresses. It is always necessary to allow an additional amount of material to take care of possible hidden defects. Due to its homogeneous properties, metal possesses many advantages over wood.

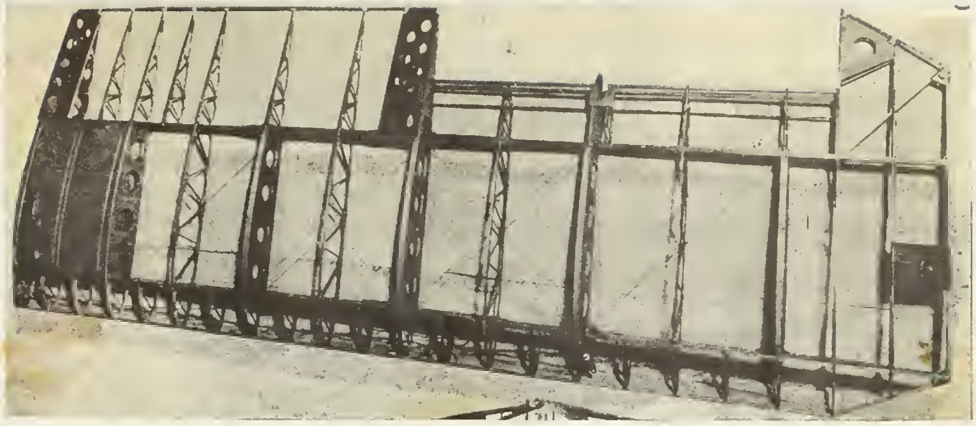


Figure 20

View of wood wing

Figure 20 shows an uncovered wing constructed of wood. This wing is made up of the following components: The front and rear spars running the entire length, or "span", of the wing, forming the main structural members of the wing. Between these spars are ribs extending from the leading to the trailing edge. The purpose of these ribs is to transmit lifting forces on the wing surface, or "skin", to the spars; and also to maintain the shape of the airfoil which is so important in producing lift. Since the shape of the leading edge of the airfoil is exceedingly important, we often find small nose ribs located in between the main ribs, and in front of the front spar, as shown, in order that the fabric, when applied to the wing, will not sag between the main ribs and in this way alter the shape of the leading edge. These small ribs are often replaced by a single piece of thin wood called "cap-strips," extending from the top of the front spar to the leading edge. They are called "false

ribs" and carry no structural loads, being used merely as formers for the upper surface of the leading edge.

The lateral control surface, the "aileron," is located near the wing tip at the trailing edge of the wing. For this reason we find that the main ribs are cut off at a third spar, called the "false spar," and it is to this false spar that the aileron is hinged. The cut out for the aileron is clearly shown.

These ribs appear exceedingly light and fragile, which indeed they are, the weight of a rib six feet long very seldom being more than six or eight ounces; but it is interesting to note that when attached to the wing as shown, with load properly applied, they support loads of as much as three hundred pounds.

In order to make this wing rigid, it is necessary to introduce bracing wires, called "drag wires," placed diagonally between the spars as shown. These wires are made of hard steel and when tightened make the wing exceedingly rigid. However, tightening these wires produces a tendency for the spars to pull in at the point of attachment, and for this reason it is necessary to strengthen the ribs at these points. These ribs, called "compression ribs," are distinguished from the main ribs mainly by the fact that they have been reinforced either with plywood or by longitudinal wooden members running between the spars. The compression ribs shown are reinforced with plywood. In some cases, however, these ribs are replaced by steel tubing, called "compression members."

The leading edges of wood wings usually consist of a half round wooden member running the entire length of the wing to which all of the ribs are attached.

It is to be noted that this attachment is accomplished by the use of casein glue. This is a dry powder manufactured from milk, which, when mixed with water in the right proportion and applied, produces a joint which is stronger than the wood itself. Two wooden members glued together by use of casein glue, when subjected to a bending or compression load, never break in the joint but always in the wood. Casein glue is used in the fabrication of all structural wooden members and due to the fact that it is also waterproof, its use in the manufacture and repair of aircraft is universal.

The trailing edges of these wooden wings usually consist of a metal "U" channel attached to the trailing edges of the ribs by means of small nails.

The completed wing forms an exceedingly light structure, but one which on the other hand is capable of sustaining a considerable load. The average load on wings of this type is usually about fifteen pounds per square foot; and a wing panel twenty feet long by six feet wide would carry a load of about eighteen hundred pounds.

This average load, however, represents merely the applied load in normal flight, whereas it may be exceeded many times due to inertia forces in acrobatic or in rough weather flying. It is, therefore, customary to design wings for private airplanes

with factors of safety in the neighborhood of 6, and we thus find that these wings are often subjected to loads of well over ten thousand pounds. It is difficult to believe, when looking at the internal structure, which appears rather fragile, that it is capable of sustaining loads of this magnitude.

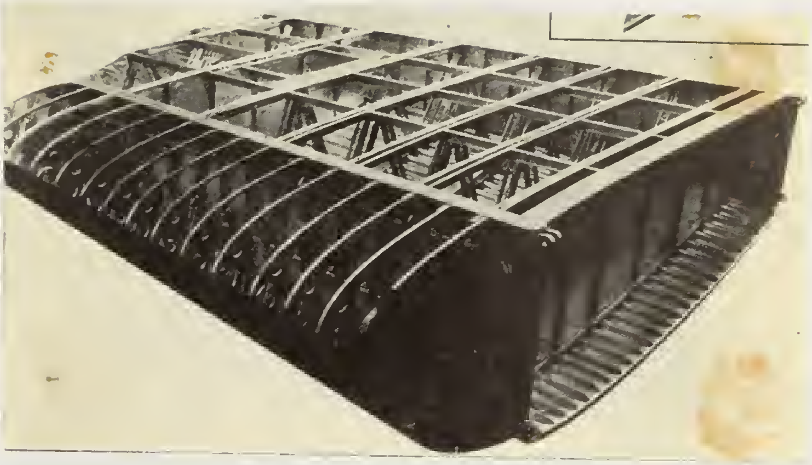


Figure 21
View of metal wing

Figure 21 illustrates very clearly the difference between metal wing construction and wooden wing construction. It is to be noted that the two main spars described previously have been replaced with a miltiplicity of spars. In some modern transport planes, we find as many as eight or ten spars along the span of the wing. On the other hand, we also find in some metal airplanes a type of wing construction called "monospar construction" in which all the load is carried by a single spar, located near the center of pressure of the airfoil. This construction

has been made possible through the use of metal and results in a considerable saving in weight.

Covering and Finishing

In general, wings are covered with three types of material, namely, fabric, plywood, and metal. The original coverings for airplane wings consisted of paper impregnated with fish glue. The fish glue was used to make the paper airtight and to reduce the friction of the air passing over its surface. The wing covering must necessarily be airtight, due to the fact that a vacuum exists above the upper surface, and should the covering be porous, air leaking into the vacuum from the under side of the wing would partially destroy the lift caused by this vacuum.

This combination of paper and fish glue obviously was not practical, since it was not waterproof, and it was replaced successively by silk, linen, and at the present time, Grade A cotton cloth.

Grade A cotton cloth consists of unbleached, long, stable mercerized cotton, the fibers of which should be at least one and one-quarter inches long. Army and Navy specifications call for ninety threads per inch in both the direction of warp and fill. A one-inch wide strip of fabric must be capable of withstanding a direct pull of ninety pounds.

This fabric is sewed up into the form of an envelope, and slipped over the wing and then attached to the wing by means of "rib stitching." After the fabric is attached to the ribs in

this manner, the fabric is impregnated with a cellulose compound known to the trade as "dope." This dope serves the purpose of making the fabric airtight, taught, and watertight. To produce a smooth, high luster finish, it is necessary to apply as many as twelve coats of this dope. Between each application and after the dope is dry, each coat must be rubbed down with fine sandpaper. This produces a glossy finish which reduces skin friction to a minimum.

The dope used on the first four or five coats is usually clear, whereas pigmented dope is used for the final coats. Pigmented dope is produced by mixing into clear dope certain colored pigments. Up to 1914 all airplanes were finished with clear dope, no color being used. The average life of the cotton cloth under these conditions was approximately three months due to the fact that ultraviolet light from the sun destroyed the fibers of the cloth, thus making it dangerous to use.

During the World War airplanes were painted for camouflage purposes, and it was found that this painting very materially increased the life of the fabric. In present day practice, after the first coats of clear dope have been applied, several coats of dope mixed with aluminum powder are applied, the purpose of this application being to protect the fabric from the rays of the sun. After this so-called "silver" dope has been applied, the pigmented dope is sprayed on, which not only helps to preserve the fabric, but also materially improves the appearance of the airplane. It has been found that this combination results

in increasing the life of the fabric to more than three years, and airplanes are no longer finished in clear dope.

The use of plywood for wing covering is at the present time limited, although it provides an excellent surface, particularly with respect to the maintenance of the contour of the airfoil as well as its life. Probably one of the leading users of plywood covering was the Fokker Company, originally located at Hassabrook Heights, New Jersey. Many of their airplanes, now ten years old, are still flying with the original plywood intact.

One advantage which plywood possesses when used for wing covering in addition to its long life is the fact that no internal bracing wires are needed due to the fact that the plywood itself is sufficiently rigid to absorb all drag forces on the wing. This materially reduces the maintenance, although the first cost of the wing is quite high. A wing without internal drag wires is called a "skin stressed wing."

Metal used for covering aircraft wings is usually aluminum alloyed with copper, magnesium, and manganese. This forms a material commonly known in the aircraft industry as duralumin, although technically duralumin is an alloy of a specific amount of aluminum and copper, being approximately 95% aluminum, 4% copper, 0.5% magnesium, and 0.5% manganese.

It is interesting to note in this connection that the metallurgists have provided the aircraft industry with a material which on a weight strength basis is far superior to steel,

although the materials used are soft and devoid of any particular strength. Dural, as it is usually called, must be carefully heat treated before use, in order to obtain the benefit of its full strength.

Dural covered wings are also skin stressed, and this type of wing is used in practically all of the modern transport airplanes. There is, however, a serious disadvantage to the use of this material for when damaged, it cannot be repaired but must be replaced. We find that for this reason modern wing construction is sectional in character in order that replacement may not be too costly.

FUSELAGES

The fuselage of an airplane is defined as the body in which are housed the passengers, cargo, and crew, and in some cases also the engine, although this is not always the case, since in many airplanes engines are placed outboard on the wings.

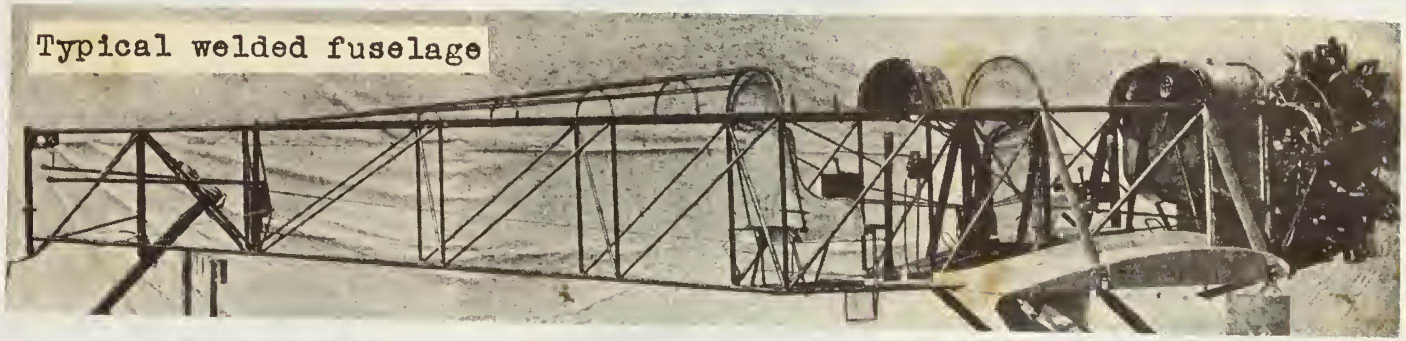
At the present time, there are only two general types of fuselage construction being used, namely, the steel tube fuselage, and the monocoque, or skin stressed fuselage.

Fuselages prior to the World War were constructed of wood, and even minor accidents resulted in serious damage to the airplane structure. At the present time, no fuselages of this type are found in airplanes manufactured in the United States.

Steel Tube Fuselages

The steel tube fuselage shown in Figure 22 is typical of this type of construction. In general, it consists of four longitudinal members called "longerons," and a series of short bracing tubes welded in between the longerons. This tubing consists of a mild low carbon steel or chrome molybdenum steel having fairly thin side walls. The thickness of the side wall depends upon stresses to which the tubing is subjected, but is very rarely over 0.120 inches. Tubing is generally oxy-acetylene welded, although at the present time experiments are being conducted with the use of electric arc welding in order to speed up manufacture.

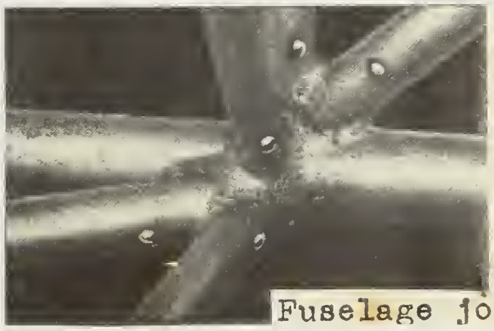
After the welding of the fuselage has been completed, it is



Typical welded fuselage

Figure 22

necessary to protect both the inside and outside of the tubing against oxidation. Protection inside is afforded by drilling small holes in the tubing through which is poured a hot, light varnish having a trade name of "Lion Oil," completely filling the inside of the tube. After thus coating the inside of the tubing, the varnish is then drained out through these small holes. The holes are then welded up to exclude all moisture. A typical fuselage joint showing the small holes after being welded is shown in Figure 23.



Fuselage joint

Figure 23

The outside of the tubing is protected by a coat of rust-proof paint covered in turn by a coat of dope-proof paint, and the whole covered with one or more coats of this same Lion Oil in which has been mixed a bronze or aluminum powder. The powder colors the Lion Oil and any uncovered sections of tubing may be readily detected.

After the fuselage has been completed, it becomes necessary to give it shape, that is, to provide it with streamlining in

order to reduce its air resistance. Streamlining is not built into the fuselage structure due to the fact that this would very materially increase its weight. The streamlining takes the form of light wooden or aluminum stringers, which run longitudinally along the fuselage attached to formers. When completed, the bulk of the fuselage, as shown in Figure 24, is distinctly greater although the weight added in producing this effect has been only a relatively few pounds.

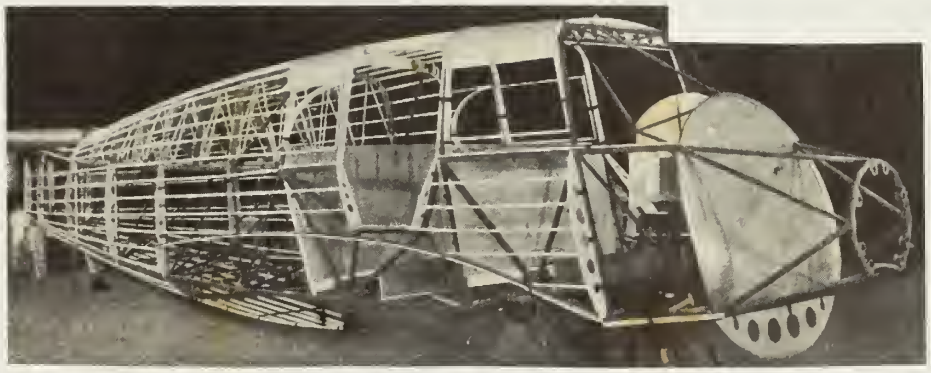


Figure 24
Fuselage with fairing attached

One of the structural difficulties facing the designer of fuselages is the discontinuity of the longitudinal structural members due to the fact that it is necessary to provide a means of entrance to and exit from the airplane. In the case of cabin airplanes, this presents a fairly complicated engineering problem since, as will be noticed in Figure 24, the opening for the cabin door is quite large. Considering also the fact that in

many airplanes a door is provided on the opposite side, it can be appreciated that careful stress analysis is necessary in order to insure the structural safety of the fuselage.

Due to the noise produced by engines and propellers, it is now necessary to introduce sound proofing into the airplane. Sound proofing is placed between the fuselage structure and the stringers mentioned above. In carefully designed sound proofing systems, the noise level has been reduced to the point where conversation in a normal tone of voice can easily be carried on. A considerable amount of research has been conducted during the past six or seven years involving this question of sound proofing. It is exceedingly difficult to exclude noise due to the fact that the whole airplane is an integral structure, which transmits the vibrations from the engine into the cabin. However, present day transports with the motors removed from the fuselage have a much lower noise level, and this problem has now been satisfactorily solved. Incidentally, one of the problems in this respect was the elimination of the noise of the air rushing past the windows at speeds in excess of three hundred miles per hour, this high velocity being due to the propeller slip stream.

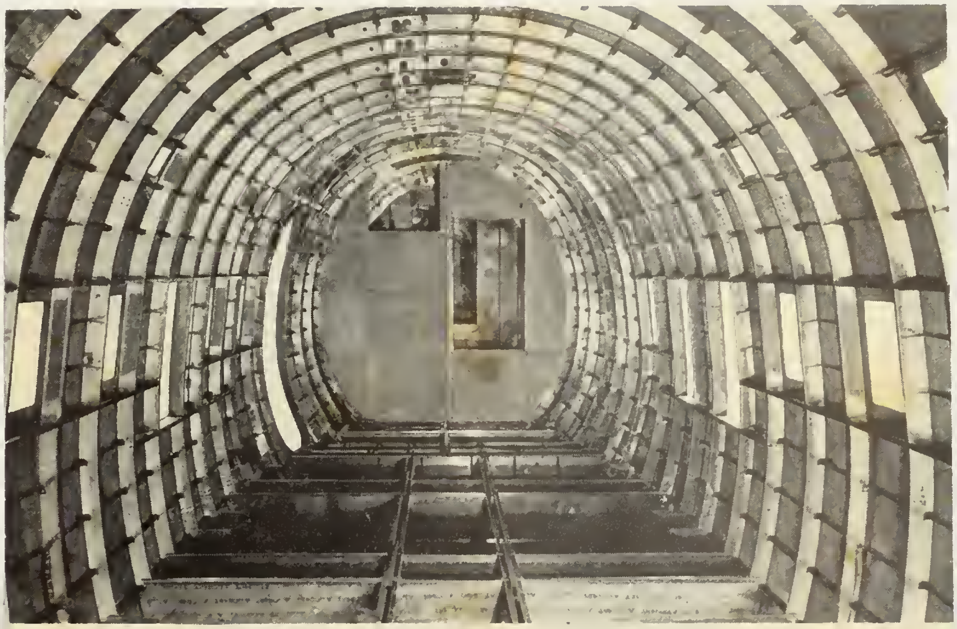
Monocoque Type Fuselages

In 1911 the French developed the "monocoque" type fuselage, which, at that time, was given the name of "eggshell" fuselage. This name was not inappropriate because all of the structural strength of these fuselages is almost entirely in the shell of

the fuselage itself, and its rigidity is derived mainly from its shape.

These fuselages were manufactured for many years out of plywood, which was wrapped around circular wooden bulkheads, but at the present time no fuselages of this type are being produced.

A picture of the interior of the Douglas DC-4 fuselage, of metal monocoque construction is shown in Figure 25. It shows very clearly the basic principles of construction. The particular advantage of this type of construction lies in the fact that there are no interfering structural members in the interior, thus leaving the designer entirely free in his arrangements for passenger comfort.



Douglas interior view of fuselage

Figure 25

It will also be noted that in this type of construction,

the insertion of doors in the fuselage presents no particular structural problem since the door represents merely a cut out in between two adjacent bulkheads. These fuselages are covered by an aluminum alloy known to the trade as "24ST."

The only finish which these fuselages receive is an interior coating of corrosive-resisting paint. The exterior is merely polished and left entirely free of any finish except a moderate amount of decorative painting.

Stresses in Fuselages

In the design of fuselages, the engineer first determines the loads to which the fuselage is to be subjected, and then designs the members in the fuselage to take this load with a suitable factor of safety.

These loads and stresses may be analyzed as follows:

The most severe loads to which the fuselage is subjected are the localized loads, during landing, at which time the entire force retarding the airplane is concentrated at the points of attachment of the landing gear struts and the tail wheel.

Considering the fact that the gliding angle of the average fully loaded airplane is approximately ten to one, we find that the vertical velocity at the point of contact with the ground is about six miles per hour. The average landing speed is sixty miles per hour, and shock absorber travel is usually not over twelve inches. Therefore, airplanes weighing many tons and having a downward vertical velocity of about six miles per hour

must decelerate to zero miles per hour in a travel of not over twelve inches. This results in concentrated loads of many tons presenting one of the most difficult design problems of skin stressed monocoque type fuselages.

At the present time, the design of load distribution under landing conditions is based upon engineering experiment rather than upon scientific fact. We find that many complicated methods have been suggested, but none of these have proven to be accurate under all conditions.

In addition to the loads described above, we find the fuselage also subject to considerable twist, particularly when both the rudder and elevator controls are used at the same time. For this twisting force, we must compensate in steel fuselages by using diagonal members, whereas in a monocoque type fuselage these stresses are easily abosrbed because of the nature of its construction.

The engine unit is the largest single concentrated load carried by the airplane. High powered modern aircraft engines at the present time weigh considerably over half a ton, and this load concentrated at the front of the fuselage or wing presents another problem to the engineer. (See Figure 26.)

Combined with the force of gravity we find also the propeller thrust as well as the torque of the engine all contributing to the problem of construction.

The part of the structure to which the engine is attached is called the engine mount, and the constructional methods of

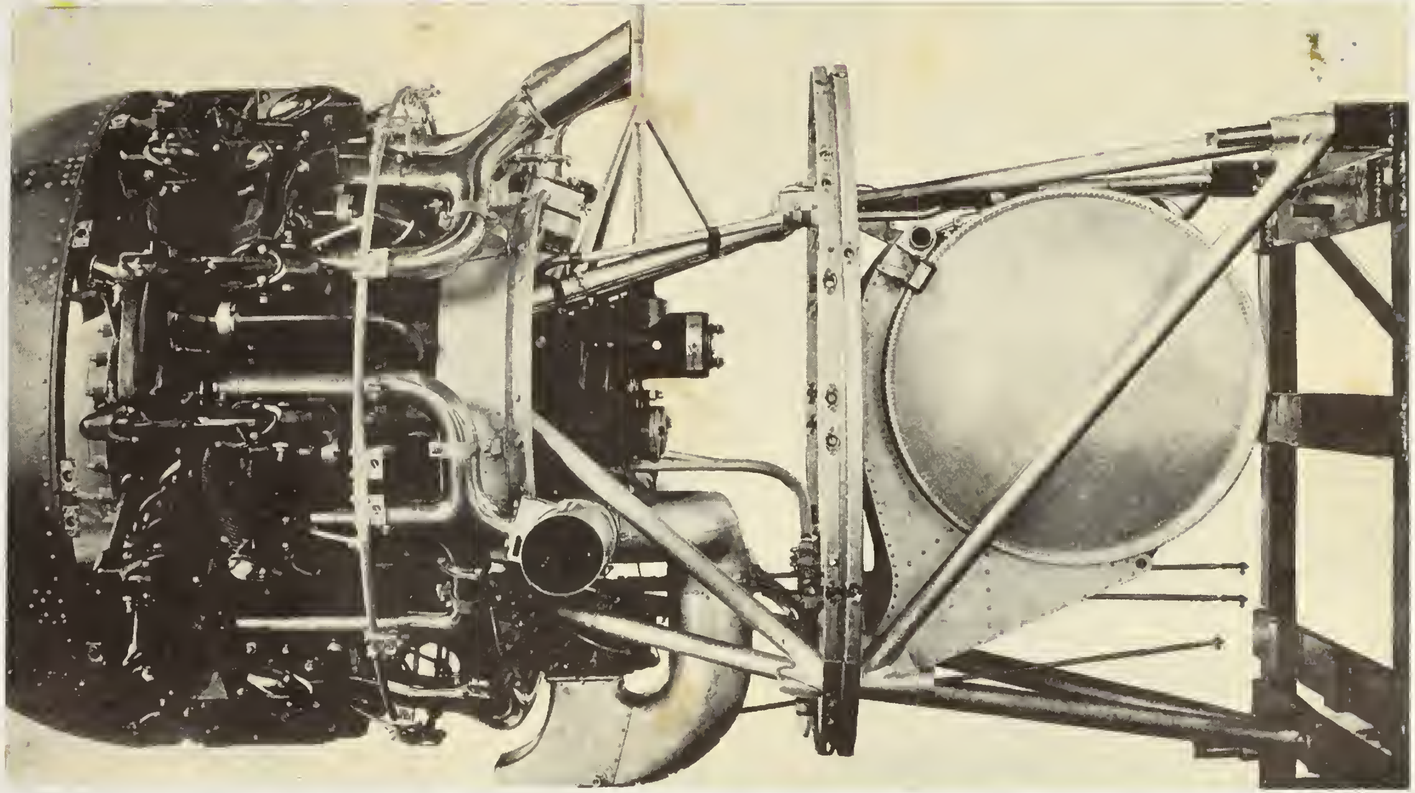


Figure 26

Motor mount construction

distributing these loads is indicated very clearly in Figure 26.

It will be noticed in this figure that the construction is of the cantilever type, heavily braced against landing loads. Tubing for engine mounts usually has considerable side wall thickness as well as outside diameter. It is very often heat treated to increase its strength.

Continual inspection of the motor mount is necessary to detect fractures caused by crystallization of the steel since the continued vibration tends to realign the molecules within the steel. If not discovered, this might result in a loss of the engine during flight. This would cause a considerable movement of the center of gravity toward the rear of the airplane, causing it to become excessively tail heavy thus preventing effective control.

Recent Developments

At the present time, there is under construction an experimental airplane using the monocoque type fuselage constructed of thin sheets of wood wrapped around wooden bulkheads. The whole is impregnated with a material having a rubber base, and the fuselage then baked under pressure. Recent tests have shown that this produces a monocoque type fuselage which is exceedingly rugged, has a surprisingly great durability and is of comparatively low cost. One of the tests to which this type of fuselage was subjected was submersion in water for an entire year. At the end of this period there appeared to be no deterioration

of the material whatsoever.

It is also proposed that wings be constructed in the same manner. Due to the rigidity of the finished structure, it will apparently be possible to eliminate all structural members on the interior of the wing. Should this prove successful, it will not only materially reduce the first cost, but also the maintenance. The author has noted in the press during the past few months several statements that a similar process has been used in Germany for the production of military aircraft.

UNDERCARRIAGES

The undercarriage, or landing gear, of an airplane may be said to be the only part of the airplane that does not contribute toward the problem of flight. Its function is merely to support the airplane when it is on the ground, and once in the air, this undercarriage not only loses its usefulness but produces drag, thus reducing speed. During the early days of transatlantic flying, Brown and Alcock (1919) flew from Newfoundland to Ireland. Immediately after take-off, the undercarriage was dropped in order that the engine might be relieved of the necessity of expending gasoline in overcoming its drag. Landing in this case was effected on the under side of the fuselage, a maneuver which is not particularly hazardous on smooth ground.

Modern airplanes dispense with the drag of the undercarriage by folding it up into the wings or fuselage and in this manner reduce by approximately fifteen percent the total drag on the airplane. This, however, does not result in a fifteen percent increase in speed, since it will be remembered that the air resistance of the entire airplane increases at the square of the speed. We do find, however, a very material improvement, the speed increasing until the increased drag on the fuselage and wings is equal to the reduced drag of the retracted undercarriage.

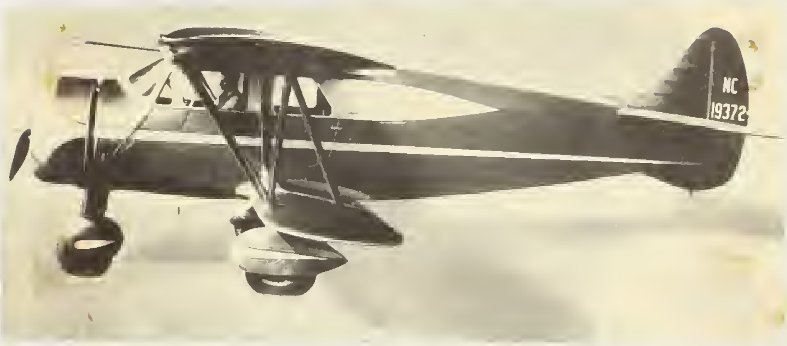
In order to insure that undercarriages have been properly designed and built to overcome landing stresses, the Civil Aeronautics Authority may require that airplanes be drop tested.

This dynamic landing gear test consists of an eighteen to twenty-four inch drop of the fully loaded airplane or its equivalent with the airplane so arranged that the load will be taken entirely by one wheel, that is, the airplane has its lateral axis tipped so that it lands upon one wheel. This simulates landing with one wheel low, which is the usual landing condition when the airplane is landed cross-wind.

The type landing gear used depends mainly upon the size of the aircraft, and it always has incorporated in it some form of shock-absorbing strut, usually of the combination air and oil type. It is to be noted that no undercarriages using steel springs for shock absorption are used since a steel spring is basically not a shock absorber, but simply a cushion. An airplane with this type of undercarriage would, upon landing, impart its energy to the steel springs and they would then return this energy to the airplane, causing the airplane to bounce in an uncomfortable and dangerous manner. Shock absorbers should be built in such a way that the energy absorbed is not returned to the airplane. Shock absorbers used are usually of the hydraulic type in which a jet of oil is forced through a small hole, thus converting the mechanical energy of the airplane into heat energy.

As mentioned previously, undercarriages represent, in the unretracted position, approximately fifteen percent of the total air resistance of the airplane; thus, for high speed airplanes, it becomes necessary to reduce this to an absolute minimum. In

the process of speed development, the first attempt to decrease the undercarriage resistance was in the use of streamline tubing, and streamline covering for all exposed parts. The second step consisted of streamlining the tires by the use of metal streamline called "Pants." (Figure 27) The last and final step consisted of retracting the entire undercarriage, including struts and wheels, into the fuselage or wings in such a way that its drag was entirely eliminated.



Waco "N" showing wheel "Pants"

Figure 27

In order to obtain a complete elimination of all drag forces incident to the use of an undercarriage, it is also necessary that the spaces or "wells" into which the undercarriage retracts should be covered so that no eddy currents are produced due to flow of air into these pockets. On most airplanes this is accomplished by an ingenious arrangement of thin metal surfaces, which automatically close these wells when the undercarriage is retracted. These surfaces can best be described as being similar to double swinging doors which open when the

undercarriage is let down, and remain in the open position until the undercarriage is retracted. In this way the underside of the wings and fuselage present a perfectly smooth surface to the flow of air, and we may say that the direct drag of the undercarriage is thus one hundred percent eliminated.

An indirect drag, due to the weight of the undercarriage, however, is still present and may be described as follows: should the airplane be relieved of the weight of the undercarriage, the angle of attack for sustained flight might then be slightly reduced and this reduction of the angle of attack would result in a decreased drag of the airfoil. The magnitude of this decrease, therefore, represents the indirect drag caused by weight of the undercarriage.

It is obvious that retracting mechanisms must be positive in their operation, particularly with respect to the ability of the pilot to lower the undercarriage in preparation for a landing. Numerous cases have been reported where the pilot has been unable to let down the undercarriage and it has therefore been necessary to land the airplane with the undercarriage in the "up" position. This often results in considerable damage to the airplane although no cases have been reported where fatalities have been caused due to this type of landing.

In order to insure positive operation, undercarriages raised and lowered either by means of hydraulic pressure or electric motor are supplemented by a hand operated mechanism, and this dual control has practically eliminated all cases of jamming of the undercarriage mechanism. In addition to the possibility of landing with the wheels up, due to the inability

of the pilot to lower them, many instances are also recorded where airplanes have landed with the wheels in their retracted position due to the fact that the pilot has forgotten to lower them. In order to prevent this occurrence, all airplanes having this type undercarriage must now be provided with a definite indicating mechanism in the cockpit to warn the pilot that the wheels are up. In some airplane installations the designer has even gone so far as to provide a stop on the throttle arm so that with the wheels in the retracted position it is impossible for the pilot to shut off the engine. This stop then becomes a positive reminder to the pilot, since all landings must be accomplished with the throttle in idling position.

Wheels and Brakes

Airplanes manufactured today are all equipped with brakes since this makes possible accurate control of the airplane while "taxiing" and reduces the length of roll on the ground after landing, thus making it possible to land in smaller fields. However, brakes must be judiciously applied since too much braking tends to cause the airplane to nose over.

In airplanes equipped with three-wheel undercarriages, however, brakes may be applied with considerable force since the wheel located in the nose of the airplane will prevent this nosing over.

Tires used on wheels are all of the full balloon or semi-balloon construction, having pressures as low as seven pounds per square inch. These low pressure tires aid materially in

reducing the shock of landing.

It is interesting to note that the greatest tire wear occurs in the landing procedure, since just before contact the angular velocity of the wheel is zero and an instant later it has been accelerated to the speed corresponding to the landing speed of the airplane, which is usually about sixty miles per hour. This scuffing action of the tires against the ground results in considerable wear and is the controlling factor in the life of tires.

Practically all improvements in the operation of aircraft result sooner or later in unforeseen problems attendant to this improvement. This is true in the case of the retractable undercarriage. To wit: large airplanes are now equipped with tires having a diameter as great as six feet and containing a very considerable amount of air under pressure. These extremely large tires, when folded up into the tire well, which in large airplanes is usually located in the wings, provides another hazard which must be overcome since a blowout in a tire of this size when enclosed might well result in excessive stresses in the wing structure.

ENGINES

General Operating Conditions

The airplane is at a considerable disadvantage as compared to other modes of transportation due to the fact that the weight of the structure and all operating parts decrease the useful load which the airplane can carry. As an extreme case may be cited some of the early transatlantic flights, when the airplane was so loaded with fuel that no useful load could be carried. Commercial operation of aircraft under these conditions is impracticable.

In the case of automobiles, busses, street cars or trains the weight of the structure does not materially reduce the amount of useful load which can be carried since these loads are supported by the ground and energy of the power plant is used almost entirely for propulsion. In the case of the airplane, however, the power of the engine is used not only for propulsion but for producing the lift necessary to maintain the airplane in the air. An analysis of airplane weights and useful loads indicates that a useful load as great as the weight of the airplane itself is unusually high. This condition would result in fifty percent of the power developed by the engine being used for maintaining the airplane in flight, and the other fifty percent for moving useful load.

For the above reasons it is necessary that the engine, which forms the heaviest single component, must be constructed to

produce the maximum horsepower per pound of engine. This requirement has resulted in the reduction of the weight of airplane engines from twenty pounds per horsepower in the case of the early models to less than one pound per horsepower in the very latest type engines. Even with this low weight of one pound per horsepower many of the larger engines weigh considerably more than a half ton.

One of the essential differences between an airplane and an automobile engine lies in the fact that the average load on an automobile engine is approximately twenty percent of its rated horsepower. This seems to be quite low, and is due to the fact that an automobile engine very seldom operates at its maximum horsepower and then only for very short periods. The airplane engine, on the other hand, must operate continuously at nearly its maximum horsepower for long periods and this results in increased thermal and mechanical stresses, making it necessary for the engine manufacturers to use materials of exceedingly high tensile strength. Not only this, but the engine must be made with precision, and the combination of expensive material and the high cost of labor necessary to obtain this precision makes the price of airplane engines quite high. The cost of large aircraft engines is approximately $5.00 per horse power, making the cost of a one thousand horsepower engine $5000. The unit cost of the smaller engines is much higher.

The average life of aircraft engines is approximately three thousand hours and is gradually increasing. At first thought

the above life would seem to indicate a rapid depreciation on the part of the aircraft engine, but we find that this compares very favorably with an automobile engine. In making the comparison, let us assume the life of an automobile engine to be sixty thousand miles, and on the basis of an average driving speed of twenty miles per hour, the automobile engine would be completely depreciated at the end of three thousand hours. To complete the comparison, we must also consider the mileage covered by the airplane engine in the same length of time, and assuming a rather low speed of 120 m. p. h., we find that the aircraft engine, in three thousand hours, has covered a distance of 360,000 miles, or a distance six times as great as that covered by the automobile engine. It will be noticed from the above that on the basis of miles of service, the aircraft engine is far superior to the automobile engine.

Principles

On the basis of operating cycles, internal combustion engines may be divided into two groups,namely, the two and the four cycle engine.

In the two cycle engine the various events are so arranged that all of the cylinders fire every revolution, whereas in the four cycle engine it requires two revolutions of the engine to fire all of the cylinders. It would seem, therefore, that on the basis of the above the two cycle engine would be superior to the four cycle engine, since in the case of an eight cylinder engine, eight power strokes would be obtained per revolution

whereas in the four cycle engine only four power strokes would be obtained per revolution. However, in spite of the larger number of power strokes produced by the two cycle engine, its efficiency is relatively low, for the efficiency of an internal combustion engine is in a large proportion due to its initial compression pressure and this, in the case of the two cycle engine, is quite limited.

In Figure 28 the positions of the piston and the various strokes of a four cycle engine are shown, and may be described briefly as follows:

In Figure 1, with the engine rotating clockwise, the piston is moving down, reducing the pressure within the cylinder so that air is forced through the carburetor picking up gasoline on its way. This is called the "intake stroke." At the bottom of this stroke the intake valve is closed and the piston comes up, compressing the gases and preparing them for ignition. This is called the "compression stroke." At or near the top of the compression stroke a spark is produced in the cylinder and the highly compressed mixture of gasoline vapor and air is ignited and burns rapidly, in this way raising the pressure. This high pressure (approximately eight hundred pounds per square inch) forces the piston downward, in this manner converting the heat energy of the gases into mechanical energy at the shaft. This down stroke of the piston is called the "power stroke." Near the end of the power stroke the exhaust valve is opened and the piston, now driven by the inertia of the rotating parts, forces

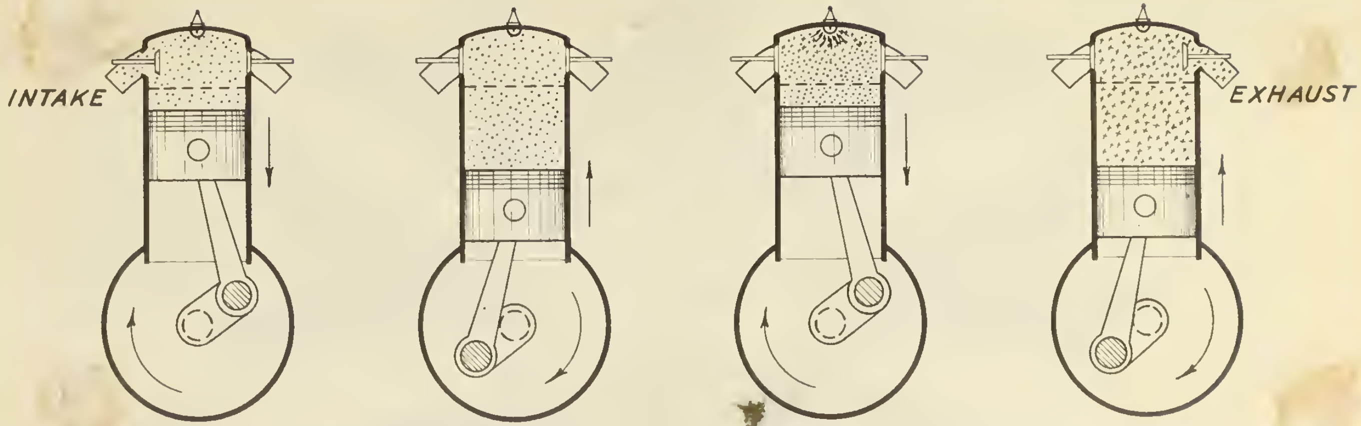


Figure 1 Figure 2 Figure 3 Figure 4

Figure 28

Four cycle engine

the exhaust gases out through the exhaust port. This stroke is called the "exhaust stroke," and the engine has now completed one cycle of events.

A stroke is defined as a movement of the piston from one extreme position to the other, and it will be noted therefore that the cylinder just discussed required four strokes for one complete cycle of operation. For this reason it is called a four stroke cycle engine, usually foreshortened and called merely a "four cycle" engine.

It is to be noted that power is produced in this engine during but twenty-five percent of its operating cycle, and that during the other seventy-five percent of the time the engine is being driven by the inertia of the rotating parts. For this reason a single cylinder four cycle engine does not operate at constant speed but increases its speed during the power stroke and decreases its speed during the other three strokes. This variation of speed is compensated for somewhat by means of a fly wheel which stores up energy during the power stroke and gives it back during the other three strokes.

It is possible to increase the smoothness of operation of four cycle engines by increasing the number of cylinders, and in the case of six or more cylinders we find that power is being continuously delivered by more than one cylinder, and in this way the rate of change of speed is considerably decreased.

In the case of aircraft engines, the propeller acts as a very satisfactory fly wheel. In the design of an internal com-

bustion engine, these variations in speed and torque must be considered particularly with respect to the crank shaft, since they set up tortional vibration.

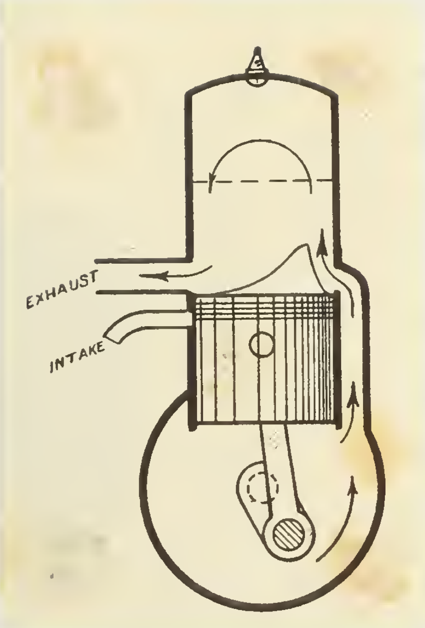


Figure 29

Two cycle engine

Figure 29 shows a two cycle engine about to begin its power stroke. Let us assume for the moment that the cylinder is full of a mixture of gasoline vapor and air, ready for compression, and the piston coming up causes these gases to be compressed, but only after the two ports shown on the sides of the cylinder have been covered. It is to be noted herewith that this engine is not equipped with the conventional type poppet valve but has ports which are uncovered by the downward movement of the piston. It is also to be noted that the upper edge of the exhaust port

is slightly higher than the upper edge of the right hand intake port. The intake port located on the left hand side of the engine is only uncovered by the piston in its extreme upper position.

Assuming, therefore, that this piston is moving upward on a compression stroke, the next event will be the firing of the fuel, causing the piston to move downward on a power stroke. Following this power stroke, the first event which occurs is the uncovering by the piston of the upper edge of the exhaust port, allowing the high pressure gases within the cylinder to move out through the exhaust port. At the same time we will assume that the crank case has during this operation been filled with a new mixture of gasoline vapor and air, and since the crank case is air tight, the downward movement of the piston on the power stroke compresses this mixture. After uncovering the exhaust port, the piston now uncovers the intake port at the right hand side of the cylinder and the gases in the crank case under pressure are now forced upward into the cylinder. It will be noted that a deflector is located on the top of the piston to prevent these fresh gases from blowing straight across the upper surface of the piston out through the exhaust port.

It will also be noted that intake occurs nearly simultaneously with exhaust and that when the piston starts its upward motion the cylinder is once more full of a mixture of gasoline vapor and air.

The gasoline vapor is introduced into the crank case during the last part of the compression stroke and the first part of

the power stroke since during this time the intake port shown immediately below the exhaust port is uncovered, and the upward movement of the piston has created a partial vacuum in the crank case,making possible a flow of air through the carburetor into the crank case.

This engine requires only two strokes to complete its entire cycle of operation, and is therefore called a "two cycle" engine. This type of engine has no poppet valves and is devoid of valve operating mechanisms and quite inexpensive. On the other hand, its output is limited by the restricted capacity of the crank case pump, and there is an extensive mixing of the fresh charge and burned gases due to the necessarily curved path of the fresh charge through the cylinder. Thus the engine is inefficient, not only for the above reason but as stated before, due to the fact that a high initial compression is not possible since the compression stroke cannot begin until the piston has moved upward in the cylinder a sufficient distance to cover the exhaust port.

The four cycle engine, on the other hand, begins its compression at the bottom of the stroke and in this way we are able to raise the compression pressure and increase the engine efficiency. At the present time there are no two cycle aircraft engines in use in the United States, although a number of two cycle engines are being used abroad.

Power Output

Two general methods are used for the determination of the horsepower output of an internal combustion engine. The first is a measurement of the brake or shaft horsepower by means of a proney brake or an electric dynomometer. These measure the horsepower delivered at the crank shaft. A second method is the determination of indicated horsepower or the heat energy of the gas converted into work within the combustion chamber. It is measured by means of a device called an indicator which makes it possible to obtain the average pressure in the combustion chamber during the cycle. Since one horsepower is defined as 33,000 foot pounds of work per minute, this horsepower may be obtained as follows: the force is equal to the average pressure on the top of the piston in pounds per square inch multiplied by the area of the piston in square inches. The distance through which this force acts may be obtained by multiplying the length of the power stroke in feet by the number of power strokes per minute, the latter being equal to the number of revolutions per minute miltiplied by the number of cylinders, divided by two for a four cycle engine since in a four cycle engine it requires two revolutions to produce one power stroke. The above results in the so-called horsepower formula:

$$H.\ P. = Plan/33{,}000$$

where P = average pressure in pounds per sq.in.
l = length of stroke in feet
a = piston area in square inches
n = number of power strokes per minute

This horsepower, due to the fact that it is obtained by the use of an indicator, is called the indicated horsepower and differs from the brake horsepower by the amount of mechanical friction, windage and pumping losses.

Engine Efficiency

The consideration of internal combustion engine efficiency is complicated by a number of factors, and in order to analyze engine performance properly efficiency must be broken down into a number of classifications, as follows:

THERMODYNAMIC EFFICIENCY. Thermodynamic efficiency is the actual efficiency of the engine under consideration divided by efficiency of a theoretically perfect engine operating on the same cycle and having the same ratio of compression. By the use of this efficiency it is possible to determine how close a particular engine comes to the ideal engine, and we find that on the average there is a difference of from between ten to twenty-five percent in the efficiency of the actual as compared with the theoretical engine.

INDICATED THERMAL EFFICIENCY. The indicated thermal efficiency is the ratio between the indicated horsepower and the energy in the fuel consumed during the same time. The energy consumed can be determined from the fuel consumption and is equal to the number of pounds of fuel consumed per hour multiplied by the calorific value of the fuel in B. T. U. per pound.

The formula becomes:

$$\text{Eff.} = \frac{\text{I. H. P.} \times 2545}{\text{lbs. fuel per hour} \times \text{B.T.U. per lb.}}$$

where 2545 represents the B. T. U. equivalent of one horsepower hour.

MECHANICAL EFFICIENCY. The ratio between the brake horsepower and the indicated horsepower:

$$\text{Mech. eff.} = \frac{\text{B. H. P.}}{\text{I. H. P.}}$$

It is to be noted that the mechanical efficiency is a measure of the mechanical losses in the engine, that is, the losses between the piston and the shaft. These losses include, in addition to the friction and windage of the moving parts, losses in pumping the fuel into the engine and the loss caused by driving the auxiliaries such as the magneto, generator, fuel pump, etc.

OVERALL EFFICIENCY. Overall efficiency is the ratio between the brake horsepower and the fuel horsepower, and furnishes a factor for determining the conversion of chemical energy in the fuel into mechanical energy at the shaft.

COMBUSTION EFFICIENCY. Combustion efficiency is a measure of the completeness of combustion and is the ratio of the heat liberated by combustion to the total chemical energy in the fuel.

VOLUMETRIC EFFICIENCY. Volumetric efficiency is a measure of the amount of air pumped into the engine during the intake stroke. As the speed of an engine is increased, the drop in pressure due to the resistance of the carburetor, intake manifold and valve openings increases, and we find therefore that

the pressure in the cylinder at the end of the intake stroke becomes less and less. For this reason the weight of the cylinder charge is reduced, resulting in a decrease in horsepower. The volumetric efficiency is determined by dividing the weight of the charge by the weight of air equal in volume to the piston displacement at standard atmospheric pressure and temperature. The volumetric efficiency also decreases as the throttle is closed since the closing of the throttle increases the pressure drop due to the air-flow past the throttle valve.

Component Parts

Internal combustion engines may be considered to consist of the basic structure of the engine, namely, cylinders, pistons, valves, connecting rods, crank shaft and crank case, to which are added a number of independent systems, all designed for the purpose of making the engine operate.

These systems are as follows:

a. A carburetor and induction system for the purpose of vaporizing fuel and mixing this fuel with the proper amount of air, and delivering it to the cylinder.

b. Ignition systems for the purpose of igniting the fuel after the charge has been prepared for combustion.

c. Lubricating systems for the purpose of preventing excessive mechanical wear, to reduce mechanical losses in the engine, and in the case of aircraft engines, to assist in cooling the interior of the

engine, particularly the piston.

d. Cooling systems for the purpose of keeping the parts of the engine exposed to high temperature gases from becoming overheated.

e. Starters and generators to serve as a means of starting the engine and for keeping the battery used for starting and lighting purposes charged.

We may now review each of these six systems in some detail.

CARBURETOR. Carburetors used on aircraft engines have certain specific functions to perform and these must be performed under varying conditions of altitude and temperature. A curve showing the relation between the air fuel ratio of an engine and its output in horsepower indicates that the maximum horsepower occurs at an air fuel ratio of about twelve pounds of air per pound of fuel. On each side of this maximum horsepower position we find a decrease in horsepower due either to the fact that the mixture is richer, that is, having less than twelve pounds of air per pound of fuel, or that it is leaner. In the case of "take-off", it is highly desirable that the engine deliver its maximum horsepower in order that any obstruction at the end of the field may be safely cleared. Under certain conditions, the pilot may require full power and the carburetor should then also deliver an air fuel ratio of twelve to one.

Airplanes, however, are seldom operated at their maximum horsepower or full throttle condition for an extended period since this would greatly increase mechanical stresses and

result in high maintenance. For this reason, once in the air with a reasonable altitude, the throttle is usually closed until the engine is delivering approximately three-quarters of its rated power. Under these conditions, therefore, a rich mixture is less to be desired than an air fuel ratio which will give the greatest mileage per pound of fuel. This, for the average engine has been found to be at a mixture ratio of about fourteen to one, and for this reason the carburetor should be so constructed that when the throttle is closed the air fuel ratio is automatically decreased to this value. This is accomplished in most aircraft engine carburetors by means of a device called an economizer.

Under full throttle operating conditions the gasoline is fed to the main nozzle of the carburetor through two small openings called the "main metering jet" and the "economizer metering jet." The size of these jets has been determined by the manufacturer for an air fuel ratio of twelve to one. When the throttle is partially closed, a small needle valve called the economizer valve closes the economizer jet so that the main nozzle is now fed through only one opening, namely, the main metering jet, and in this way the fuel flow is reduced so that the mixture ratio becomes fourteen to one.

All internal combustion engines should be able to run at idling speed, which condition obtains when the throttle is in a fully closed position. At this time the velocity of air flow through the carburetor is relatively low.

Gasoline ordinarily is forced through the main nozzle into

the air stream in the form of a spray by means of the difference in pressure between the float chamber and the throat of a venturi tube in which the nozzle is located. The float chamber maintains a constant head of gasoline within the carburetor and this difference in pressure therefore is dependent upon airflow velocity in the venturi tube which reduces the pressure in accordance with Bernouilli's Principle. We find, therefore, that a difference of pressure will exist between the float chamber, which is vented to atmosphere, and the throat of the venturi tube. The greater the air velocity through the venturi the greater will be the drop in pressure, resulting in more gasoline being discharged by the nozzle. In this way fuel flow is increased for the production of the increased horsepower as the throttle is opened.

In practice it is not possible to place the top of the nozzle at the same level as the fuel in the float chamber, due to the fact that molecular adhesion will cause the gasoline to creep over the top of the nozzle when the engine is stationary. There would then be a continuous dripping of gasoline from the carburetor. In all carburetors therefore the fuel level is kept approximately three-eights of an inch below the top of the nozzle, and for this reason no gasoline will be discharged from the nozzle until a sufficient difference in pressure exists to lift the gasoline through this head.

Under idling conditions, no gasoline issues from the main nozzle since the airflow through the venturi is too low to pro-

duce this difference in pressure and it becomes necessary to feed gasoline into the engine by some other method. The mechanism through which this is accomplished is called the idling well, which consists of a passage connecting the float chamber to a space immediately above the throttle valve. The throttle is so designed that when it is in the completely closed position a small annular passage exists between the throttle valve and the side of the carburetor. The velocity of air flow through the lower part of the carburetor is so low that the pressure below the throttle valve is practically atmospheric, whereas the vacuum above the throttle valve is exceedingly high due to the fact that the pistons are pumping air out of the intake manifold faster than the air flows in through the small annular passage mentioned above. We therefore find under idling conditions a high vacuum above the throttle valve, and gasoline flows from the float chamber through the idling well into the air flowing past the throttle valve. The opening through which this gasoline flows is called the "idling jet," and it must necessarily be small since the horsepower output at idling is merely that necessary to overcome the friction losses of the engine.

Aircraft carburetors must also be designed to provide proper air fuel ratios at high altitudes. An examination of the laws governing the drop in pressure through the venturi tube will show that the predominant factor is the air velocity, through the venturi, and not the density of the air, although density does affect it somewhat. We find, therefore, that an engine

with a satisfactory mixture ratio at sea level has its mixture becoming increasingly rich as the airplane ascends, due to the fact that although the air is becoming more and more rare, fuel is being delivered at a nearly constant rate (this is assuming the engine running at the same speed).

At ten thousand feet, therefore, the mixture becomes so rich that it is operating on the "rich" part of the mixture curve, and some means must be provided for reducing the mixture ratio in order that fuel will not be wasted and that the maximum horsepower may be obtained.

There are in general two methods of obtaining this result. The first consists of placing an air by-pass around the venturi tube so that some of the air going through the carburetor is by-passed around the venturi, resulting in a decreased air velocity in the venturi, with a resultant decrease in vacuum at the throat of the venturi. This reduces the flow of gasoline while at the same time maintaining the same airflow, resulting in a leaner mixture.

A second method by which this same result may be obtained is to connect the air space in the float chamber to the venturi tube through a valve, at the same time placing a second valve in the atmospheric vent to the carburetor float chamber. By proper operation and synchronization of these two valves, the partial vacuum at the throat of the venturi may be transmitted to the float chamber and in this way the difference in pressure controlling the fuel flow is reduced resulting again in a de-

creased fuel flow and therefore a leaner mixture.

Within the past year a carburetor has been produced which, using the second method outlined above, performs this function automatically. However, on nearly all engines used at the present time, this control is manual and adjustment is made by means of an altitude control in the cockpit.

It might be pointed out that the use of the altitude control is accompanied by a certain amount of hazard since the effect is reversed when the airplane descends from high altitudes to sea level, namely, if the mixture has been adjusted for a ratio of fourteen to one at ten thousand feet, then at sea level the mixture will be much too lean. Lean mixtures result in a "popping" back into the intake manifold when the throttle is suddenly opened--an effect similar to that which obtains when an automobile engine is started in cold weather.

A pilot operating his airplane at ten thousand feet with the proper amount of altitude adjustment closes the throttle when he wishes to descend. He places the airplane in a glide which may be in a straight line but is usually in the form of a spiral, and during the entire descent there is no necessity for the use of the engine. Upon approaching for a landing, the pilot may, under these conditions, find that through misjudgment the airplane will not be able to clear obstructions at the approach end of the field. It is therefore necessary for him to apply power. If, during his glide he has neglected to bring the altitude adjustment back to a position corresponding to sea level operation,

he finds that upon opening the throttle the engine "pops back" into the intake manifold, due to the fact that it is too lean, and before it is possible for him to bring the altitude adjustment to its proper position it may be too late.

Contrary to common belief, aircraft carburetors are not designed to operate during inverted flight. Airplanes do fly upside down, but as a general rule upside down flying consists merely of rolling the airplane over on its back at a considerable altitude and then gliding in an inverted position. The design of a float chamber to furnish fuel to the engine in both an upright and inverted position would be extremely complicated. There is also the consideration of fuel supply in the inverted position since if the airplane is equipped with a gravity feed fuel system, inverted flight places the fuel supply below the carburetor.

Airplanes have been designed for inverted flight with full power, but these airplanes are equipped with two independent carburetors, one in the normal position, and the other in an inverted position so that in inverted flight the airplane still operates on a carburetor in normal position.

BATTERY AND MAGNETO IGNITION SYSTEMS. Ignition systems in modern automobiles usually consist of a battery, a single ignition coil, an interrupter or breaker, and a distributor.

The principle of such an ignition system is comparatively simple. It consists of two independent electrical circuits, the first called the low tension circuit, consisting of a battery, switch, primary coil, and an interrupter which has shunted across it a condenser. This condenser prevents arcing at the interrupter points and also intensifies the induced electromotive force in the secondary. The second electrical circuit, called the secondary, consists of a high tension coil, distributor and safety gap.

The single coil previously mentioned in which is found both the primary and secondary winding, consists of an iron core about which are wound a relatively small number of turns of insulated wire. This forms the primary circuit of the coil. Wrapped around this primary coil and insulated from it is a second coil having a large number of turns of very fine insulated wire. This forms the secondary. Connected to one side of the high tension coil is a distributor used for the purpose of distributing the high tension electromotive force generated in the coil to the cylinder spark plugs in the proper order.

When the ignition switch is closed, a current is established in the primary circuit flowing in series through the battery, switch, primary coil, interrupter points, and finally back to the opposite side of the battery, either through a wire, or

through the engine structure. In the latter case, the system is said to be grounded. In this case, it is necessary to ground one side of the battery. Current is therefore established in this completed circuit through the primary coil, and this current in the primary coil produces a flux which surrounds not only the primary but also the secondary coil. When the engine is turned over, a cam mechanically connected to the engine operates so as to break the circuit at the interrupter points. This interruption of current causes the flux produced by the primary coil to collapse, cutting across the turns of the secondary coil, inducing an E. M. F. proportional to the speed at which the magnetic field collapses, the strength of the magnetic field and the number of conductors in the secondary which it cuts.

The condenser connected directly across the interrupter points causes a very rapid collapse of this magnetic field, and we find therefore that the condenser is essential not only for reducing maintenance by eliminating arcing, but also for the production of a high E. M. F. at the terminals of the secondary coil. This E. M. F. should be equal to approximately twenty-five thousand volts if a proper spark is to be obtained at the spark plug points within the cylinder. One side of the secondary coil is grounded and the other side is carried to the center point of a distributor. Around the periphery of the distributor head are found contact points, one for each cylinder, and the high tension current flows from the center point to the outer contact points through a rotating brush. The rotating mechanism

must be timed, not only with respect to the engine, but also with respect to itself, so that when the No. 1 cylinder is ready to begin its power stroke, the following conditions obtain:

1. The cam must be ready to open the interrupter points.
2. The distributor brush must be in a position to carry the induced E. M. F. to the contact point connected to No. 1 cylinder, since this is the only cylinder ready to fire.

The average ignition system is timed in such a way that the spark is produced approximately 25° before the piston is at the top of its power stroke. This is called "spark advance" and is made necessary by the fact that the mixture of gasoline vapor and air should not explode, but burn at a rapid rate. However, the rate of combustion is relatively slow compared with the average speed of rotation of the engine. At 1800 R. P. M. it requires only one-sixtieth of a second to complete the power stroke, and the fuel must therefore be ignited before the piston reaches the top of the stroke, since otherwise the piston will be down at the bottom of the power stroke and the exhaust valve open before the gases are completely burned, resulting in a considerable loss of power and an overheating of the engine. This overheating is due to the fact that the cylinder walls are exposed to burning gases during the entire power stroke, and part of the exhaust stroke as well.

The rapidity of burning may be increased by raising the compression pressure, but it is found that above a certain pressure

the fuel explodes, creating severe stresses and excessive heating within the engine. This instantaneous combustion is called "detonation" and is often present in engines having heavy carbon deposits in the combustion chamber. This deposit reduces the clearance volume, raising the compression pressure to the point at which "detonation," that is, knocking, occurs.

Some fuels have poor detonating qualities which means that they can be used only in engines which have a low compression pressure. Since aircraft engines must deliver a maximum amount of horsepower per pound of engine, we find that their compression pressures are high, and for this reason a fuel of exceedingly high "anti-knock" qualities must be used. The introduction of certain materials, one of which is "Tetra-Ethyl-Lead" improves the anti-knock qualities of the fuel.

At the present time, we find a few aircraft engines using the battery and coil ignition previously described. At least ninety-eight percent of all aircraft engines in the United States are equipped with magneto ignition. There is no good engineering reason why this should be so, but it is probably due to the fact that early airplanes used magnetos exclusively in order to save weight, and careful engineering by the manufacturers produced magnetos which are capable of operating under very adverse conditions. All magnetos used on airplanes at the present time will operate satisfactorily even when immersed in water.

Investigation of records of forced landings for a number of

years discloses that the magnetos are responsible for less than one-tenth of one per cent of all engine failures. Given such a remarkably reliable piece of equipment, it is to be expected that an attempt to convert pilots to the use of coil ignition would be an exceedingly difficult task.

Basically, a high tension magneto differs from the battery and coil ignition in only one fundamental respect, namely, that the electrical energy, instead of being supplied by a storage battery is obtained by generation within the magneto itself. The magneto is a completely self-contained unit having all of the parts of the battery ignition system, except the battery, and for this reason its weight is considerably less than the combination coil, ignition and battery. The weight differential in favor of the magneto has disappeared in the present day airplane since practically all modern airplanes are equipped with batteries for lighting purposes, and the weight of the battery could therefore not be charged against the ignition system. However, we find coil ignition making very slow progress in spite of the fact that it is probably just as reliable as magneto ignition. As previously mentioned, this is undoubtedly due to "pilot resistance," since having flown many years with magnetos functioning perfectly under adverse conditions, they resist almost unanimously any attempt on the part of the engine manufacturer to substitute battery ignition.

Airplane engines are equipped with dual ignition systems, consisting of two magnetos and two completely independent high

tension wiring systems. Individual grounding switches are used for each magneto. Each engine is equipped with two sets of spark plugs, one set located in the front of the cylinders, being served by one magneto, while the other set located in the rear is served by the second magneto.

This duplicate set of spark plugs and wiring not only serves to increase the reliability of the ignition system, but since ignition occurs simultaneously at two points, combustion is more rapid. This results in a more rapid increase in pressure and therefore a greater horsepower output. It is customary, after engines have been warmed up in preparation for flight, to run them for a few moments at wide open throttle, shutting off first one magneto and then the other. This checks the condition of each individual ignition system separately. Operating the engine on a single magneto results in a drop of approximately ten percent in horsepower output.

LUBRICATION. Lubricating systems in automobile engines have a single function to perform, that of lubricating wearing parts. However, in the case of the aircraft engine we find that the lubricating system must perform another service, namely, that of reducing the internal temperature of the engine. Due to continuous high output operation with the resultant large consumption of fuel, operating temperatures of aircraft engines are quite high, and for this reason the piston, the most difficult part of the engine to cool, becomes exceedingly hot. Due to

this high temperature, materials having high heat conductivity must be used, in order to prevent overheating of the piston, and for this reason aluminum pistons are almost universally used.

However, without considerable cooling, even aluminum would overheat, and for this reason large quantities of oil are pumped through the lubricating system. The cranks as they rotate throw this oil up into the pistons which are provided with fins on the inner side. After absorbing heat, the oil collects in the crank case and is then pumped through an oil radiator in order that this heat may be extracted. In this way, the lubricating system serves to cool the engine internally. In order to increase the quantity of oil used and in this manner keep the engine temperature within safe limits, the bearing clearances of aircraft engines are quite large. This allows large quantities of oil to flow through the engine.

Lubricating Principles.

In order to secure satisfactory lubrication it is necessary that an oil film be established between wearing surfaces. This oil film should be of sufficient thickness to prevent the high spots of the bearing metals from rubbing. Due to its crystalline structure, even polished metal has these high spots. The viscosity of the lubricant is an important factor in determining the thickness of this oil film and since the operating temperatures of aircraft engines are quite high, aircraft engine lubricating oils with an S. A. E. viscosity of eighty are quite common, whereas in the case of automobile engines, oils having a viscosity of more than forty are seldom used. Since the

viscosity of oil, however, is dependent not only upon its chemical composition, but also upon its temperature, we find that the viscosity of the heavier aircraft engine lubricating oils at the operating temperature is approximately the same as the viscosity of the lighter automobile engine oils at their operating temperatures.

It is to be noted that the problem of oil dilution, that is, the mixing of gasoline and lubricating oil, is not a problem in the aircraft engine. Gasoline introduced into the cylinders tends to condense when the cylinder temperatures are low, and this condensed gasoline then leaks past the piston rings and mixes with the oil. Gas dilution is serious in the case of automobile engines, since it reduces very materially the viscosity of the oil, and if continued, will result in a viscosity insufficient to maintain the oil film required for proper lubrication. On the other hand, although oil dilution does occur in the case of aircraft engines, their operating temperatures are sufficiently high to evaporate all gasoline as rapidly as it is deposited in the oil, and whereas automobile engine oil tends to become thinner during use, aircraft engine oil becomes heavier. This increase in viscosity is due to the distillation of the lighter and more volatile parts of the lubricating oil as well as to the absence of crank case dilution.

Lubricating Systems.

Lubricating systems in aircraft engines may be divided into two general classifications, namely, "wet" and "dry sump" engines.

In the wet sump engine, the sump being formed by the lower part of the crank case, the lubricating oil used is contained in the crankcase in a manner similar to that of the automobile engine. However, due to the higher heat generated, the crankcases are generally made of aluminum with cooling fins located on the outside of the crankcase and the engine cowling is so arranged that a blast of air from the propeller circulates past these fins. This type of system is limited to engines of low horsepower output in which the cylinders are arranged in a vertical row, and in an upright position. These are classified as "in-line," "vertical" and "upright" engines. Cylinders in air-cooled engines of this type are individual units, and not cast in a single block, and the inertia stresses caused by the moving pistons must be absorbed by the crankcase. They are, therefore, made quite deep since the resistance to bending is in this way materially increased. The lower ends of the connecting rods are for this reason usually well above the oil level, and all lubrication is accomplished by means of a pressure pump which forces oil to the bearings. The oil which is spilled out from the crank bearings is then thrown up into the pistons for cooling purposes.

In order to prevent the oil from flooding the engine in inverted flight, a fine wire screen is placed above the oil just below the lowest level of crank throw so that when the airplane is in an inverted position, the oil flows through this screen rather slowly, thus preventing the pistons from being suddenly deluged with oil.

Dry sump engines, on the other hand, are so arranged that the lubricating oil, after completing its journey through the engine, falls into the crankcase, whence it is pumped through some form of oil cooler back to an oil tank in which all of the oil except that passing through the engine is stored. This is the type of lubrication system used in all radial and inverted engines. It necessitates, in addition to the pressure pump used in the wet sump engine, a low pressure scavenging pump, the purpose of which is to extract the oil from the crankcase and pump it back into the oil reservoir as rapidly as it collects in the sump.

In examining the structure of a radial engine it might seem that the lower cylinders would receive an excess supply of oil, and for this reason carbon up rapidly. The sump in this type engine consists of a small rectangular box, located between the two lower cylinders, and cast as an integral part of the crankcase. Much of the oil falling down from the upper cylinders finds its way into the lower cylinders, but since the pistons are moving up and down rapidly, this oil is pumped over into the sump as rapidly as it falls. For this reason we find that there is no appreciable difference between the accumulation of carbon in the upper and lower cylinders.

Considering first the more complicated dry sump systems, we find that they consist generally of the following parts:

a. A storage tank, which, according to the Civil Aeronautics Authority regulations, must have a capacity equal

to one-sixteenth of that of the gasoline tanks.

b. A high pressure pump for a forced feed lubrication of all bearings.

c. A pressure relief valve located in the pressure line to the bearings for the purpose of maintaining constant oil pressure at the bearings. This pressure relief valve is necessary due to the fact that capacity of the oil pump must exceed the requirements of the engine. The quantity of oil flowing through the engine is governed by bearing clearances, and as these bearings wear and the clearances increase, the resistance to the flow of oil decreases. If, therefore, the oil pump were only of sufficient size for proper lubrication of a new engine, then as the bearing clearances increased, due to wear, its capacity would be insufficient to maintain full oil pressure. We find, therefore, that oil pumps have a capacity far greater than that of the lubricating system, and for this reason a pressure relief is required. When the pressure produced by the pump reaches a predetermined amount, the relief valve opens, allowing the oil by-pass back to the suction side of the pump. In this way, as the engine wears, the relief valve by-passes less and less lubricating oil and the oil pressure at the bearings is maintained at the constant value.

d. A pressure gauge in the high pressure line, located in the pilot's cockpit.

e. A scavenging pump for returning oil to the oil reservoir.

f. An air-cooled radiator, equipped with a manually operated by-pass which is used in conjunction with an oil temperature indicator. This temperature indicator and by-pass control is located in the cockpit and provides the pilot with a means of keeping the oil temperatures constant in spite of varying atmospheric conditions. Operation of this manually controlled by-pass maintains oil viscosity at all times, at its proper value.

During cold winter weather, it is often found necessary to by-pass all of the engine oil around the oil radiator, and in addition to wrap all of the oil lines and oil tank with sheet asbestos in order to prevent the oil from becoming too viscous.

Unless the airplane is kept in a heated hangar, it is necessary in extremely cold weather to drain all of the oil from the lubricating system after the airplane returns to the ground. Otherwise, it becomes too viscous to be moved by the pump, and the engine, upon being started, receives no lubricating oil.

COOLING SYSTEMS. Aircraft engines may be generally divided into two distinct types, depending upon the method used for cooling. They are: air-cooled engines, and liquid cooled engines.

During the early days nearly all aircraft engines were

water cooled, whereas at the present time in the United States we find the air-cooled engine predominating. The particular advantage of the air-cooled engine is the elimination of all piping necessary for connections to and from the radiator and circulating pump, resulting in an increased reliability of operation. Also, the elimination of the water cooling system materially reduces the total weight of the engine, which reduction in weight, as mentioned before, is highly essential. The disadvantage of the air-cooled engine lies mainly in the increased air resistance due to the fact that the cylinders must be exposed directly to the air stream although the difference in air resistance is reduced somewhat due to the fact that even the water cooled engine, although it can be housed entirely within the fuselage, uses a radiator similar to that used in an automobile which is placed in the air stream. In the case of racing planes, this form of radiator is sometimes converted so that it consists of two thin sheets of brass approximately four one-thousandths of an inch thick between which the water circulates. This flat surface radiator is then used for the wing covering, and in this way the entire drag of the radiator eliminated. At the present time "prestone," due to its lower freezing as well as its higher boiling temperature, has replaced water in liquid cooled aircraft engines.

For military purposes the air-cooled engine has one distinct advantage. Since the cylinders are arranged around a single short crankshaft, the length of the engine is materially

decreased, thus reducing its moment of inertia. This is clearly shown in Figures 30 and 31. This makes the airplane powered

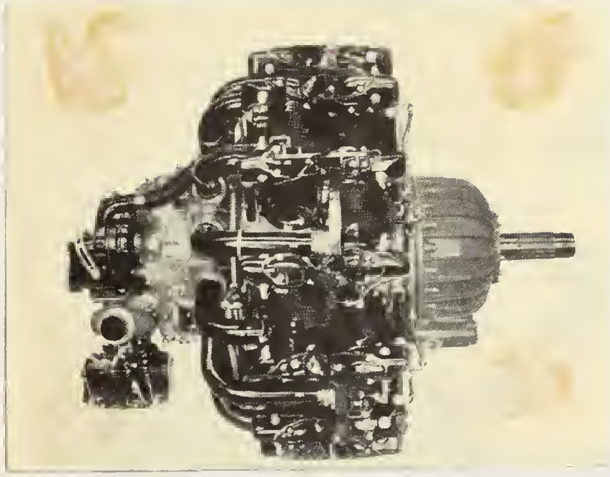


Figure 30

Twin-row Wasp

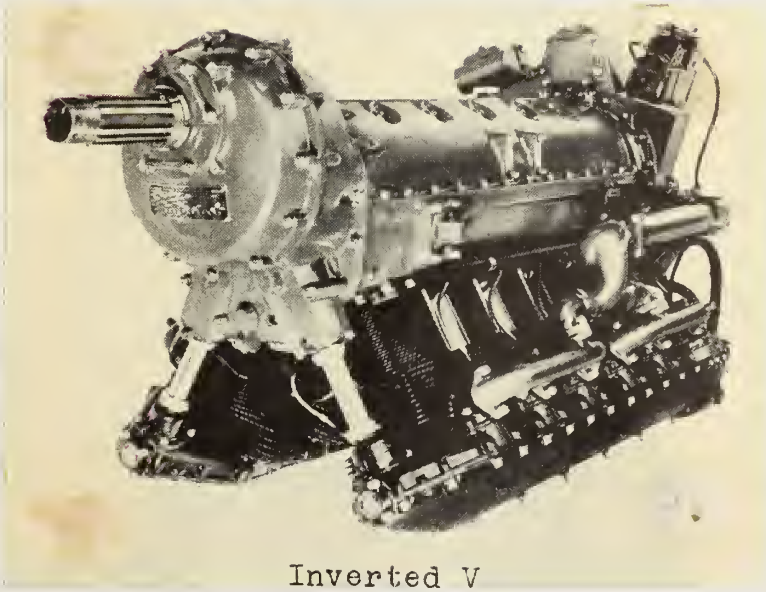


Figure 31

Twelve-cylinder Buccaneer

with an air-cooled engine much more maneuverable than in the case of a liquid cooled engine, since all liquid cooled engines are of the in-line type and must necessarily be quite long.

The air-cooled engine is particularly suited for commercial purposes because of the reduction in weight, increased reliability and the fact that freezing temperatures will not injure the engine.

GENERATORS AND STATORS. Until the development of the larger airplanes, sources of electrical current were limited to dry cells, or very light and low capacity lead storage batteries. As the size of airplanes increased, it was found that this source of electricity was entirely inadequate and it therefore became necessary to equip airplanes with generators as well as batteries. With the introduction of night flying this was particularly true since navigation lights were required between sunset and sunrise.

The first generators used were of low capacity, and the electrical system was very similar to that used in automobiles with a cut-out so arranged as to prevent the battery from discharging through the generator, when the generator voltage decreased below that of the battery, and a voltage regulator was also added to prevent overcharging of the storage battery, particularly during long daytime flights. This system is now standard in nearly all modern airplanes. The generators are all of the direct current shunt wound type, since their voltage

characteristics are such that upon short circuit, armature reaction reduces the generated electromotive force to a point at which the short circuit current does not become excessive.

These generators are usually of the three brush type in order that the generated current may be regulated to meet the varying demands made upon the system. We find these generators driven in two ways, either by means of a small single bladed propeller located in the slipstream, or connected directly to the engine through a train of gears.

The wind driven generator uses a single bladed propeller and is streamlined with the entire unit placed in the propeller slip-stream. In this way there is no mechanical connection between the engine and the generator, and at the same time the generator is continuously driven while the airplane is in the air. In order to maintain constant generator speed with varying airplane speeds, the propeller is constructed in such a way that at a determined speed, centrifugal force causes the blade to feather, thus reducing its angle of attack. This produces a governor effect, keeping the speed of the generator constant.

As the use of the radio increased, a second generator was added, this generator being a high frequency alternating current generator used solely for radio purposes. This is generally driven by means of a small, single bladed propeller as mentioned above.

The latest type generating system consists of 110 volt alternating current generator driven by an independent source of

power, usually a small air-cooled gasoline engine located inside the fuselage. This system is used for general lighting and the operation of the many mechanical devices used on an airplane such as retractable undercarriages, flaps, electric stoves, air compressors for de-icing equipment, etc. Since many of these applicances require considerable power, the saving in weight by raising the voltage has been very material. The use of a low tension six or twelve volt direct current system in the modern clipper airplane is impracticable due to the fact that the copper cables would become excessively heavy.

In order to save weight, airplane engines were originally manually started by a mechanic who spun the engine by means of the propeller. As the size of the engines as well as their compression ratios increased, they became increasingly difficult to start. Even as far back as the World War the Liberty engine, a twelve-cylinder, four hundred horsepower engine, required three men to "pull the propeller through." In addition, hand starting is exceedingly hazardous and many mechanics have been killed by falling into the propeller after the engine was started.

It would seem that in addition to the difficulty and the hazard involved, a starter would be desirable in case of engine failure while in the air. This latter condition, however, in no way hastened the use of the automatic starter for the reason that the engine does not cease turning over as long as the airplane is in the air, even after the ignition switch has been shut off. This is due to the fan effect of the air upon the

propeller which keeps the propeller turning over even after the engine has stopped firing. The resistance of a propeller idling over due to the fact that the engine has failed can be materially reduced if the engine is stopped, and since practically all four-engined airplanes land with only two engines running, it would be desirable to provide the pilot with some means of stopping the "dead" engines. For this reason, four-engine airplanes are usually equipped with brakes on the propeller hubs for the purpose of stopping engines with ignition switches shut off.

The first type of starter used was a direct connected hand crank. This starter consisted merely of a hand crank connected to the crankshaft through reduction gears and a clutch. They were quite common in 1927 and 1928, and were operated by the crank, which was turned over very much in the same manner as the crank used in turning over an automobile engine. It differs, however, from the automobile crank in that it is located at the rear and on the side of the engine and is geared down so that it requires approximately twenty revolutions of the hand crank to complete one revolution of the crankshaft. The clutch mentioned was necessary to prevent injury to the mechanic in case the engine backfired.

The next development was a hand inertia starter and consisted of a small hand driven unit containing a small fly-wheel and a clutch. In operating this particular type of starter the mechanic uses a hand crank which is connected to the fly-wheel through a system of gears. The rotation of the hand crank

causes the fly-wheel to rotate at an exceedingly high rate of speed, approximately 20,000 r. p. m., and in this way a considerable amount of inertia may be stored up in the fly-wheel. During this time, the starter is entirely disconnected from the engine. After being brought up to speed, which fact is determined by the high pitched whine of the starter, a clutch is engaged and the energy of the fly wheel transferred to the crankshaft, resulting in a rapid spinning over of the propeller for a dozen or more revolutions. If the engine fails to start, it is then necessary to repeat the process.

Simultaneously with the hand inertia starter, air starters were developed which consist of a small high pressure tank containing compressed air piped to the cylinders of the engine through an air distributor in such a way that air is admitted to the cylinder which is just beginning its power stroke and then in order to the cylinders in accordance with the firing sequence. The air tank is of sufficient capacity to turn the engine over for approximately thirty turns. In case the engine does not start before the air is exhausted, it is then necessary to resort to hand starting. The starter also includes a small air compressor which is attached to the engine, so that after starting, the air supply in the air tank may be replenished. A safety valve is provided to prevent excessive pressures. This type of starter is by far the lightest of all the starters, having a total weight, complete with piping, etc., of approximately forty-nine pounds.

Following this development, electric inertia starters were developed. This starter is similar to the hand inertia starter except that the small fly-wheel is driven by an electric motor rather than by hand. Electric inertia starters require considerable electrical power, and airplanes using this type of starter must be provided with a heavy duty storage battery which adds to the weight of the starter system.

The latest type of electric starter consists of a motor directly connected to the engine through a non-reversible clutch. Since the motors are directly connected to the engine, a considerable amount of power is required for their propulsion, and it is not economically feasible to equip even transport airplanes with storage batteries sufficiently heavy for this service. Nearly all modern transport planes use this type of starter, and the starter motor terminals are carried out to a connecting plug on the outside of the fuselage to which a large heavy duty storage battery may be connected. This storage battery is moved about on the ground by means of a small rubber-tired cart, and when it is necessary to start the engine, this storage battery is brought out to the airplane and plugged in. After starting, the storage battery is then disconnected and removed, and in this way it is not necessary for the airplane to carry this additional weight. This arrangement naturally necessitates the use of similar type battery equipment at all landing fields.

Another type of starter built especially for high pressure engines consists of a small mechanism very similar to that of a

single barrel shotgun without either the long barrel or the stock. When it is desired to start the engine, a small blank shell similar to that used in a shotgun is inserted in a short barrel through a breach which is then closed. The gases produced by the combustion of the gun powder within the starter are piped to the various cylinders in very much the same manner as in the air starter. This type starter operates without any appreciable noise and eliminates one of the disadvantages of the air starter in that the number of starting attempts is limited only by the supply of shells. The particular advantage of this type of starter lies in its lightness, and even though it is necessary to replenish the cartridge supply continuously, the total operating cost, including maintenance, probably does not exceed that of the electric starter. This would certainly be true if the saving in weight is considered.

PROPELLERS

The propeller, through years of design and experimentation, has been brought to a remarkably high degree of efficiency. At the present time we find metal propeller efficiencies as high as eighty-seven percent.

Propellers were originally constructed of wood and laminated for safety purposes. Due to the fact that wood is subject to many defects which may be hidden below the surface, it has been the practice for many years to build propellers from thin laminated sections glued together.

A propeller is essentially an airfoil section with its angle of attack increasing from the propeller tip toward the hub. This increase in angle of attack is necessary if the central part of the blade is to produce its share of the thrust. The lift on an airfoil is dependent upon the square of the speed, the angle of attack, and the camber. Since the linear velocity of the blade decreases toward the hub, the resultant loss in lift is compensated for by increasing the angle of attack and the camber. This increases the thickness of the blade toward the hub which mechanically is fortunate since the stresses due to centrifugal forces increase in the same direction.

Propellers are generally operated at approximately eighteen hundred revolutions per minute, although the most efficient engine speed is well above this value. We find, however, that propeller efficiency decreases very rapidly with an increase of

propeller speed, and in any particular propeller-engine combination, two opposing elements are involved. To increase the horsepower of the engine it is necessary that it be driven at a speed above that which produces maximum propeller efficiency.

Investigation shows that a propeller tip speed equal to the velocity of sound is the maximum at which a propeller can be economically operated. For this reason we sometimes find reduction gears used which enable the engine to run at speeds greater than that of the propeller. A gear ratio of three to two is quite common. However, this is not without its disadvantages since not only does it add weight to the combination, but a considerable amount of power is lost in the reduction gears.

The diameter and width of the blade is proportional to the horsepower to be absorbed, and we find that as the horsepower of engines increased, propeller diameters became so great that it was necessary to reduce the engine below its economical speed in order that the tip speed of the propeller should not be too high. For this reason we find high powered engines equipped with three and four blade propellers which, although not as efficient as two blade propellers, provide sufficient area for absorbing power without excessive tip speed.

It was not until 1926 that a satisfactory metal propeller was designed. This propeller was made of aluminum alloy and was superior to the wooden propeller in several respects. Since its tensile strength is greater, it was possible to make the airfoil section of the propeller tip much thinner, thus increasing its

efficiency. The blades were set in a metal hub in such a way that the pitch of the blade could be altered, making possible the adjustment of the propeller for the optimum pitch angle. In addition to the above advantages, the metal, being more homogeneous, could be much more satisfactorily designed and it was not necessary to add additional material to compensate for hidden defects.

During take-off conditions it is highly desirable that the engine deliver as large a horsepower as possible, and one of the methods of obtaining increased horsepower is to operate the engine at a high speed.

The pitch angle to give this maximum horsepower is not, therefore, the most economical operating speed since it reduces the propeller efficiency, and we find that a dual position of the propeller would be desirable--a low pitch for take-off giving maximum horsepower and therefore best rate of climb, and a high pitch setting which would give the maximum propeller efficiency for cruising.

This condition resulted in the development of several types of controllable pitch propellers. These propellers were so arranged that the blade angle could be changed by the use of a control located in the cockpit. In general there were two means of accomplishing this, one being hydraulic and the other electric. Both of them, however, gave the pilot a choice of only two positions, one for take-off and one for cruising.

For any airplane speed, the most economical point of opera-

tion would be one at which the combination propeller and engine efficiency would have a maximum value. This is found to be a condition of constant speed, and to meet this new requirement we find that all modern transport airplanes are equipped with constant speed propellers operating on a centrifugal principle in such a way that irrespective of the throttle setting, the propeller speed remains at a constant value. This forms the most efficient propeller engine combination yet developed.

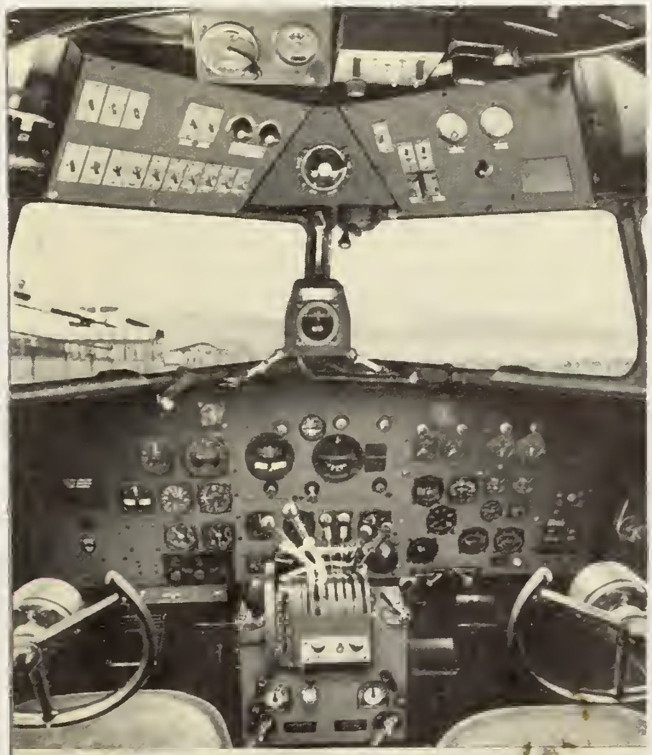
A few hollow steel propellers have been built, but up to the present time they have not been commercially successful.

The propeller always has been and still is the source of a large portion of the noise attendent to the operation of airplanes. No particular attempt is made on the part of the engine manufacturers to muffle the exhaust, since under normal operating conditions the propeller is responsible for approximately eighty percent of all the noise. This therefore forms a very fertile field for experimentation, and attempts have been made for many years to produce silent propellers, but we seem to be no nearer this goal at the present time than we were twenty years ago.

INSTRUMENTS

Early airplanes were flown without instruments of any kind except perhaps an occasional engine instrument in order that the pilot might be able to check up on the condition of his engine.

As the complexity of flying increased, however, it became necessary to add one instrument after another until the modern transport cockpit contains as many as one hundred and fifteen engine, airplane, and navigational instruments and controls. Such a cockpit is shown in Figure 32.



Douglas control compartment

Figure 32

As noted in the section on airplanes, there are certain speeds below which the airfoil is unable to maintain lift equal to the weight of the airplane, even at its maximum angle of attack, and it is therefore highly desirable that a pilot should maintain a speed in excess of this at all times. It is natural, therefore, that the first airplane instrument used was an air speed indicator to warn the pilot that he was approaching the stalling speed. As airplanes were developed and flying extended over long distances, and in conditions of bad weather, it became necessary to add an altimeter for indicating the altitude of the airplane above the ground, and also a fuel gauge to indicate the amount of fuel in the tanks. Blind flying necessitated the use of airplane position indicators; winter flying, the use of indicators to warn of icing conditions, and the continued improvement of both airplanes and engines necessitated the addition of many other necessary instruments.

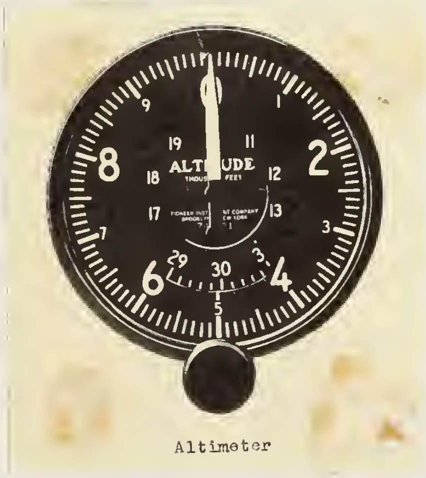
Aircraft instruments may be divided into three general classifications:

1. Airplane instruments
2. Engine instruments
3. Navigational instruments

Airplane Instruments

Under this classification are included all of the instruments necessary for the operation of the airplane. These are indicated herewith.

ALTIMETERS. Altimeters are used for the purpose of indicating the altitude of the airplane, and up to within the past three months altimeters were all built on the principle of the aneroid barometer, connected through a system of levers to a rotating hand which reads in thousands of feet. Such an instrument is shown in Figure 33. This type of altimeter which is still universally used, is subject to considerable error, due not to the mechanism itself, but to its principle, namely, that it operates on barometric pressure. In order to demonstrate this, let us assume an airplane standing on an Airport with the altimeter reading zero. If the barometric pressure now decreases,



Altimeter

Figure 33

the altimeter would indicate an increase in altitude in spite of the fact that the airplane has not moved. The error introduced by changes in barometric pressure, however, are not as serious as those introduced by the contour of the ground over which the airplane is flying. Let us assume that a pilot is flying westward in an airplane fifteen hundred feet above the city of Boston. Let us also assume no change in barometric pressure and that he flies in such a way that the altimeter continues to read fifteen hundred feet. Observing the contour of the earth between Boston and Springfield, we find an approximate rise in the elevation of the ground of a thousand feet. When reaching Springfield, therefore, the pilot, whose altimeter is still reading fifteen hundred feet, would only have five hundred feet of clearance between the airplane and the ground. This condition has resulted in many serious accidents during times when pilots were flying in fog. A knowledge of the contour of the ground over which the pilot is flying, as well as changes in barometric pressure, are therefore necessary if the readings of the altimeter are to be used intelligently.

In addition to the altitude scale, nearly all altimeters are provided with a reference scale indicating barometric pressure. When the main dial of the altimeter is rotated in such a way that the reference point on the dial corresponds to the correct barometric pressure, the error due to barometric pressure variation is then eliminated. This thumb screw is located externally on the lower part of the instrument case, as shown.

Should a pilot therefore desire to land at an airport located five hundred feet above sea level, he would obtain by radio information concerning barometric pressure at that particular airport and correct his altimeter accordingly. Since the barometric pressure readings are corrected to sea level, he would find that upon landing at this airport his altimeter would read five hundred feet.

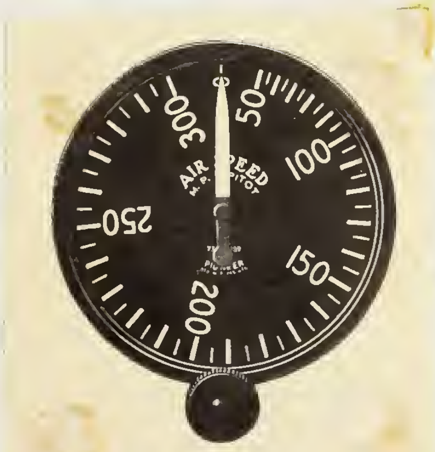
As the percentage of bad weather in which airplanes are flown has increased, it has become necessary to increase the sensitivity of the altimeter. By increasing the number of aneroid elements within the altimeter, it has been possible to produce an altimeter sufficiently sensitive to indicate altitude changes of only a few feet.

The latest development in altimeters consists of an absolute altitude indicator which indicates the altitude above the ground over which the airplane is flying. This instrument is independent of barometric pressure and operates by means of radio waves sent out from and reflected back to the airplane. In this way the hazards due to flying over unknown terrain in bad weather have been largely eliminated.

AIR SPEED INDICATORS. Air speed indicators are used for the purpose of determining the speed of the airplane in relation to the air. It is also operated on an aneroid principle and consists of an airtight case in which the aneroid is mounted. This case is connected to a pitot tube, having both a static and dnyamic pressure which is transmitted to the inside of the

aneroid. Increases in speed are accompanied by an increase in dynamic pressure which expands the aneroid, thus rotating a hand on the air speed dial.

In general practice the air speed indicators have reference marks indicating critical speeds, these speeds being "maximum safe speed," "cruising speed," and "minimum speed." The air speed indicator shown in Figure 34 does not have these reference points.



Air Speed Indicator

Figure 34

For safety, speed with relation to the air must be known, but for navigational purposes it would be desirable to have a direct ground speed indicator which would indicate to the pilot his speed over the surface of the ground. No such absolute ground speed indicator is available at the present time.

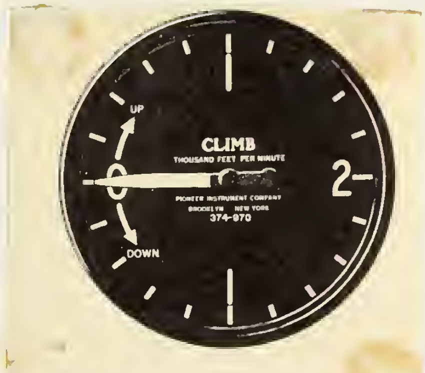
Errors in air speed indicators are caused by the fact that a decrease in air density causes the air speed indicator to read low; at ten thousand feet the instrument error is considerable.

This error, however, is subject to calculation by means of the gas laws, and we find that an airspeed indicator at ten thousand feet reading 180 m. p. h. has an error of -30 m. p. h. The corrected speed is 210 m. p. h. Pilots of all transport planes are provided with an altitude correction chart for air speed correction.

CLIMB INDICATORS. In blind landing approaches it is necessary for the pilot to have accurate information concerning the rate of descent of the airplane. The usual procedure under these conditions is for the pilot to orientate himself on the landing beam at a fixed altitude. Upon passing a radio position marker he then descends at a fixed rate for a predetermined number of seconds. He should then be over the edge of the airport at a correct altitude for landing.

This procedure necessitates accurate knowledge of rate of descent and a climb indicator furnishes this information.

The operating elements of a climb indicator consist of an aneroid, the inside of which is connected to a small air bottle. This air bottle has a small vent to atmosphere through which air slowly leaks as altitude is changed. Due to the time lag, a difference of pressure is built up on opposite sides of the aneroid so that the reading of the hand operated by the aneroid mechanism is proportional to the time lag which in turn is proportional to rate of change of altitude. Such a climb indicator is shown in Figure 35.



Climb Indicator

Figure 35

FUEL LEVEL GAUGES. Fuel level gauges are used for indicating the gallons of gasoline remaining in the tanks, and operate on both mechanical and electrical principles. In general, they are quite simple, consisting merely of some form of float which indicates directly, or which operates a sliding contact point on a high resistance which, used in conjunction with a battery and a milliammeter, will register gallons of fuel. In a few airplanes of the cabin type we find gauge glasses similar to those used on boilers which indicate the level of the liquid in the tank. These generally do not indicate the number of gallons of gasoline remaining but merely indicate the percentage of fuel left in the tank. Under these conditions, it is necessary for the pilot to have information concerning the number of hours of flying represented by a full tank of gasoline.

TURN AND BANK INDICATOR. In order that pilots maneuvering under blind flying conditions may be aware of the position of the lateral axis of the airplane, a bank indicator is necessary.

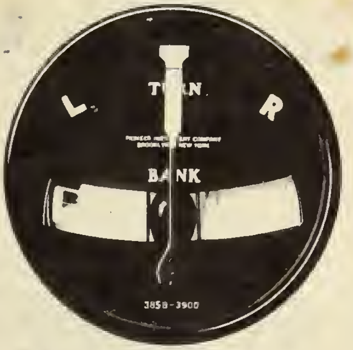
It is interesting to note, with reference to blind flying, that since all fixed reference points are missing, it is virtually impossible for the pilot to determine whether or not the airplane is turning or in which direction it may be turning, or to determine whether the airplane is in a glide or in a climb. The glide and climb can be checked by the rate of climb indicator described above, but many times a decrease in altitude may be due not to the fact that the airplane is in a glide but due to the fact that one wing is low and that the airplane is slipping sideways, and for this reason losing altitude.

In order that the pilot will be able to maintain the lateral axis in a level position, a bank indicator is provided which consists simply of a glass tube approximately two inches long in which is contained kerosene and a steel ball. The glass tube is curved upward toward the outer ends and so placed in the airplane that when the lateral axis is level the steel ball is at the center of the glass tube. A low wing, therefore, will cause the steel ball to move in the direction of the low wing, and to maintain laterally level flight it is only necessary for the pilot to keep this ball in the center position.

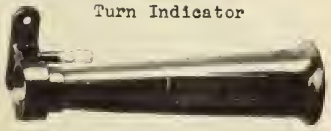
In making a proper turn, that is, a turn with the proper amount of bank to prevent the airplane from slipping, or skidding, the resultant of the gravitational and centrifugal force must be perpendicular to the lateral axis, and we find therefore that the bank indicator also assists the pilot in making turns, since an improper amount of bank either to the right or to the

left results in a movement of the steel ball from the center position.

Even with a bank indicator, it is still possible for a pilot to fly an airplane improperly under blind flying conditions. Since he has no sense of direction, due to the lack of a reference point, the airplane may, without this knowledge, be turning to the right or the left even though the lateral axis is actually level, and no change in altitude is taking place. In order to eliminate this flying error, the airplane is provided with a gyroscopic instrument called a turn indicator which indicates to the pilot whether or not the airplane is turning and if so in which direction. Both the bank indicator described above and the turn indicator are included in the same instrument, as shown in Figure 36, and are called "turn and bank indicator."



Turn Indicator



Venturi Tube

Figure 36

The turn indicator, as mentioned above, is a gyroscopic instrument, the power for the gyroscope being obtained by means of a venturi tube shown in Figure 36 which, by virtue of the vacuum it produces, draws air through the case of the turn indicator. The air, upon entering the case, passes through a nozzle and is directed against blades on a turbine type rotor, thus causing it to rotate. The gyroscope is mounted on ball bearings which are placed in a gimbal frame mounting, and rotates at a high speed.

We find that this turn and bank indicator, coupled with the rate of climb indicator, form the three essential blind flying instruments since, if the airplane is flying a straight and level course, we find the bank and turn indicator at zero and the rate of climb indicator enables the pilot to make proper turns without loss of altitude or slipping or skidding. In addition, by the use of a rate of climb indicator he may descend at a fixed rate which has previously been determined as the rate of descent from a fixed point which will bring the airplane to the edge of the airport at the proper altitude.

THERMOMETERS. Thermometers for indicating the temperature of the air outside of the fuselage are used for warning the pilot of icing conditions. The formation of ice on all exposed parts, particularly wing and propellers, may be very rapid, and presents a very considerable hazard during winter flying conditions.

Ice generally is removed by means of rubber sleeves located

on the leading edges of the wings and control surfaces, these sleeves being connected to an air pressure tank through an automatic valve. This valve during operation admits air to these sleeves, expanding them, and in this manner breaking the ice which then drops off. The valve then shuts off the air, allowing the sleeves, called boots, to deflate, and the continuous operation of this valve keeps the wing free of ice.

Propellers are equipped with slinger rings located at their hubs, through which alcohol is fed, this alcohol being deposited on the blade at the hub and carried out toward the tip by means of centrifugal force. The slinger ring is operated continuously during icing conditions.

The effect of icing is to increase materially the weight of the airplane, but a more serious effect is that of changing airfoil shape which reduces lift very rapidly. Ice formation occurs most frequently when an airplane flies through a cloud containing supercooled vapor which, upon contact with the airplane, immediately freezes. Under these conditions, ice forms at an exceedingly rapid rate, and airplanes upon which such ice begins to deposit must immediately rid themselves of this ice or descend to lower altitudes and higher temperatures. If this is not possible, then the airplane must land immediately before going out of control.

Engine Instruments

The use of the present day high compression, high altitude engine has increased very materially the number of instruments required. We find in the cockpit of the modern plane the following engine instruments:

TACHOMETER. The tachometer, which may be of the mechanical or electrical type, is used by the pilot for determining the condition of the engine before take-off, as well as to check its performance in the air.

Since the propeller is attached directly to the engine without a clutch, we find that the speed at which an airplane engine can turn over against the drag of the propeller is proportional to the horsepower output of the engine.

Assuming, therefore, that a new engine is able to turn up at 1700 r. p. m. while on the ground, we find that this speed then becomes a standard for determining the future condition of the engine, since as the horsepower of the engine decreases through use, its maximum speed at full throttle gradually decreases. Should the engine be missing on one or more cylinders, the pilot would immediately discover this fact by the reading of the tachometer with the throttle wide open.

Individual "engine-propeller" combinations operate at maximum economy, at certain speeds, and it is usually at this speed that the engine should be operated. This optimum speed, determined after a number of trial runs, is then used as a standard and the pilot is usually instructed to cruise his airplane at a

certain tachometer reading.

The tachometer is also often used to prevent operation of an engine at a speed in synchronism with the vibrational period of the propeller. Usually propeller vibration cannot be detected by the pilot while flying, and his only safeguard against operation at the vibrational speed of the propeller is the tachometer. A tachometer is shown in Figure 37.

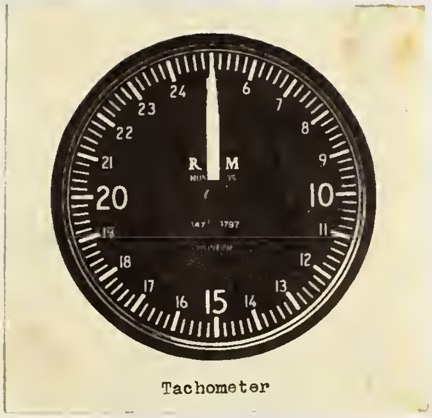
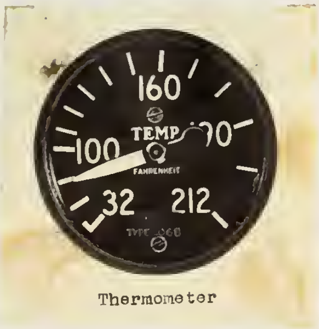


Figure 37

TEMPERATURE INDICATORS. Many types of temperature indicators are used for engines. They operate either on the principle of the thermocouple, or as in the case of oil temperature and liquid temperature indicators, by gas pressure. Oil or liquid temperature indicators are used to determine the approximate operating temperatures of the engine, since the overheating of the engine will raise either the internal oil temperature, or in the case of liquid cooled engines, the temperature of the cooling liquid. These temperature indicators inform the pilot

that some unusual condition is causing overheating of the engine. However, since both of these indicators are subject to a time lag, many airplanes are also equipped with thermocouples which are usually attached to the top cylinder at the spark plug boss. This boss is located directly on the combustion chamber and the overheating of the engine due to lack of oil, cooling medium, lean mixture or detonation is immediately indicated by this thermometer. Thermometers are also often located in the intake to the carburetor to warn of icing conditions. A common type of thermometer is shown in Figure 38.



Thermometer

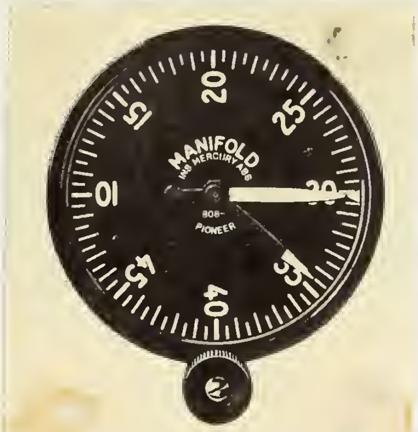
Figure 38

Under icing conditions due to the drop in pressure at the venturi tube of the carburetor, ice may form very rapidly. This formation of ice in the venturi tube has the same effect as closing the throttle valve since it restricts the flow of air through the carburetor, thus cutting down the fuel supply. This particular condition forced the English clipper, "The Cavalier," to land at sea off the Bermuda Islands.

In order to prevent this icing up, carburetors are provided with electric heaters, the purpose of which is to increase the temperature of the air before entering the venturi tube, and we find therefore that a carburetor temperature indicator is required in order to protect against the icing conditions.

OIL PRESSURE GAUGES. Oil pressure gauges are used for indicating that a proper supply of oil is being delivered to the engine at all times. It is assumed that the oil pressure corresponding to that maintained by the oil pressure relief valve indicates a proper functioning of the oil pump. Should the oil pump fail due to mechanical trouble or lack of oil, the oil pressure gauge would immediately indicate this condition.

INTAKE MANIFOLD PRESSURE GAUGES. High compression engines supercharged for altitude operation can operate at full throttle only at high altitudes, since under full throttle conditions at sea level the compression pressure, due to the action of the supercharger, becomes sufficiently high to cause severe detonation. In order that the pilot shall not open the throttle to the detonating point, an intake manifold pressure gauge, shown in Figure 39, is provided, and a pilot is instructed that the throttle shall not be opened so that the pressure in the intake manifold exceeds that pressure recommended by the manufacturers. This obtains at all altitudes up to that for which the engine is designed where the engine may be operated at full throttle, since at this altitude the supercharger discharge pressure has been reduced to one atmosphere by the decrease of suction



Manifold Pressure Gauge

Figure 39

pressure. For safety purposes the manifold pressure gauge is provided with a stationary reference hand which indicates maximum allowable manifold pressure, usually about thirty-four inches of mercury absolute.

FUEL PRESSURE AND FLOW INDICATORS. On airplanes having pressure fuel systems it is necessary to have a fuel pressure indicator to determine whether or not the mechanical fuel pump is operating properly. This fuel pressure gauge consists of a small gauge having a Bourdon tube which is connected into the fuel system between the fuel pump and the carburetor, In addition, a fuel flow meter is often used to indicate the number of gallons of fuel per hour being delivered to the engines. This latter instrument is desirable, particularly for long flights, since in the case of exceptionally high head winds it may be necessary to reduce the speed of the airplane in order to conserve fuel. The use of the fuel flow meter makes it possible

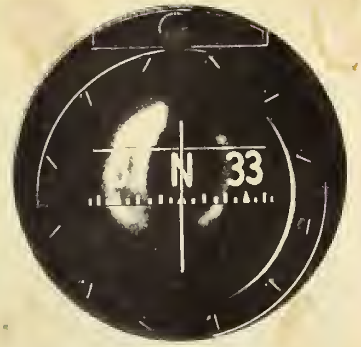
for the pilot to compute the number of hours of flight possible on the then available fuel supply.

DUPLICATION OF INSTRUMENTS. In the case of multi-cylindered engines, it is necessary to duplicate all of the above instruments for each engine, with the possible exception of the carburetor temperature indicator. This contributes to the complexity of the instrument panel board, and in many of the large airplanes all engine instruments and controls have been removed from the pilot's cockpit and are located in a separate compartment where they are supervised by an engineer. In this case the pilot signals for power in much the same manner as the pilot of a steamer.

Navigational Instruments

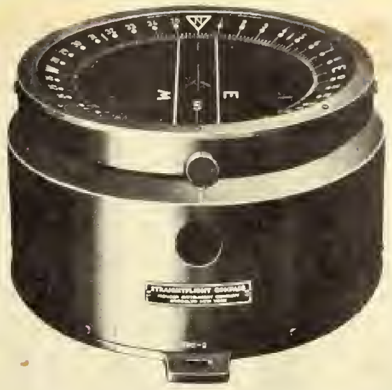
Originally the only navigational instrument used was the magnetic compass, consisting usually of a small compass card to which are attached two small permanent magnets. It is to be noted that with the exception of the four cardinal points of the compass an airplane compass card reads from zero to 360°. It is mounted on a jewel bearing and in order to provide damping, the entire compass bowl is filled either with alcohol or a white kerosene. Two such compasses are shown in Figures 40 and 41.

The magnetic compass is subject to errors of variation and deviation. Readings may be corrected for variation by reference to an isogonic chart similar to the one shown in Figure 42.



Compass - Spherical Bowl

Figure 40



Compass - Straightflight

Figure 41

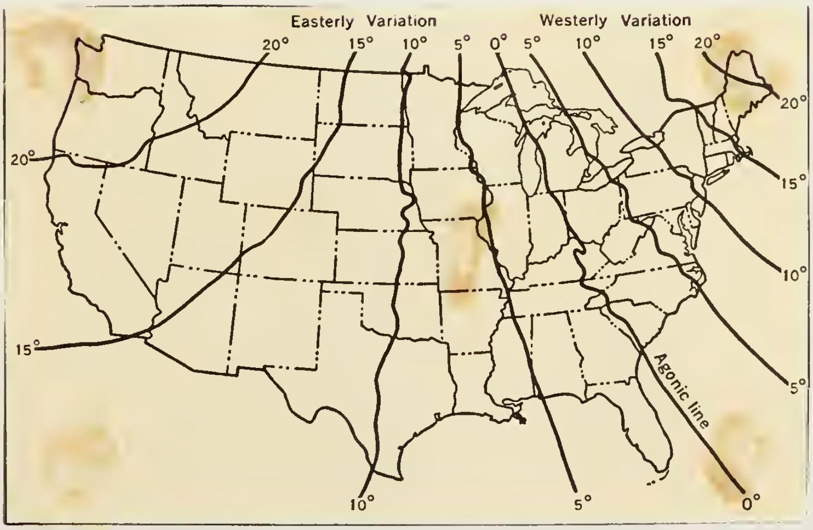


Figure 42

Errors due to the deviation may be compensated for by turning the airplane on the ground and observing the errors of the compass, these errors being due to the magnetic parts of the airplane which distort the earth's field.

In addition to these two errors, the magnetic compass is subject to a turning error due to the vertical component of the earth's magnetic field. When an airplane flying toward the north is turned, the compass card is tipped and is then subject to the effect of this vertical component which causes the compass to turn more rapidly, or less rapidly, than the airplane, depending upon which way the airplane is turning.

This effect may, in the case of blind flying, cause the pilot to "overcontrol" the airplane in making his turn, thus causing the airplane to fall out of control into a spin.

The earth inductor compass was designed to eliminate some of the above errors, although the error due to variation is still present. The earth inductor compass consists merely of a small rotating coil with a commutator so constructed that when the plane of the two brushes of the generator is placed at right angles to the earth's magnetic field, the indicated voltage is zero. When these brushes are rotated through a small angle by the turning of the airplane, a voltage is indicated on a small voltmeter in the cockpit. In order to bring the brushes back to the normal position they may then be rotated by a small hand operated crank located in the cockpit, and the angle through which the brushes must be turned in order to bring the voltage

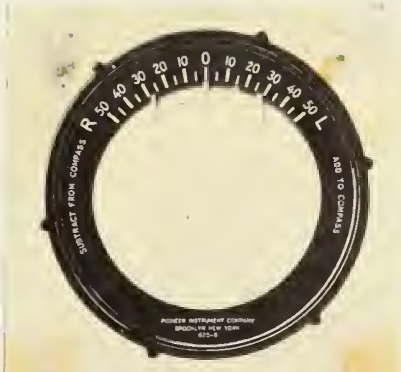
back to zero is then equal to the angle through which the airplane turned. In this manner a pilot desiring to fly due east would set his indicator at 90° by means of the hand crank, and it would then be necessary for him to point the airplane in a magnetic east or a magnetic west direction if he desired to have the brushes normal to the earth's field. In order that the pilot may determine which of the two directions, now 180° apart, that he should fly, the voltmeter is provided with the letter "R" and the letter "L" on the dial located to the right and the left respectively of the center zero voltage position. The connections of the compass are such that in flying toward the west with the indicator set for eastward flight, application of the right rudder would cause the voltmeter to show a left turn which is opposite to the direction in which the airplane is turned. Flying toward the east, however, application of right rudder causes the needle of the voltmeter to swing to the right, thus indicating to the pilot that he is going in the right direction.

The rotor of the earth inductor compass which is air driven may be located toward the rear of the airplane, away from the engine, which produces the largest distortion of the earth's magnetic field, and in this manner deviation due to field distortion may be nearly eliminated. However, the earth inductor compass is still subject to corrections due to errors of variation, and is also affected by the vertical component of the earth's magnetic field in a turn.

The gyroscopic compass for airplanes has been developed for

the purpose of eliminating errors of deviation as well as turning errors, and consists simply of a small vacuum operated turbine rotating at a high speed. This compass is not affected by the earth's magnetic field nor by turning errors, but it is subject to a gradual error due to precession. It is therefore necessary for the pilot to check continuously the gyroscope compass against the magnetic compass, but it does provide him with an accurate device for making turns. In blind flying procedure, accurate turns are quite necessary, and in order to become properly orientated on a landing beam, it is necessary for a pilot to turn his airplane through a predetermined angle. The gyroscopic compass is an essential instrument for this procedure.

The latest development is the radio compass which consists essentially of a small radio set provided with a loop antenna which may be rotated by the pilot independent of the airplane. In the older installations the loop was fixed and rotated by means of turning the airplane. It was found, however, that this interfered with the navigation of the aircraft, and the Civil Aeronautics Authority regulations now require rotatable loops. The character of a loop antenna is such that when the plane of the loop is normal to a line drawn between the airplane and the ground sending station, maximum strength signals are received. Ninety degrees from this position no signals are received, and in this way the operator of a radio compass may fix his position by taking bearings on two or more ground stations located at known points.


R 50 40 30 20 10 0 10 20 30 40 50 L
SUBTRACT FROM COMPASS
ADD TO COMPASS
PIONEER INSTRUMENT COMPANY
BROOKLYN NEW YORK

Drift Indicator

Figure 43

DRIFT INDICATOR. The drift indicator shown in Figure 43 is probably one of the simplest instruments to be found in the pilot's cockpit. It contains no moving elements and consists merely of a piece of ground glass and a lens held in place by the outside case of the instrument. The glass rotates within this case and has on it three straight parallel reference lines. The outside of the case is graduated in degrees and is placed in the cockpit so that a line drawn from the center of the instrument through the zero degree line is parallel to the center line of the airplane. The direction of this line is therefore always parallel to the direction in which the ship is headed. In using this instrument, the pilot observes the image of an object on the ground passing across the ground glass, and rotates this glass until the reference lines are parallel to the motion of this object. The reference lines are now pointing in the direction in which the airplane is moving, and the angle read on the scale is the angle between the direction of motion of the airplane and

the direction in which it is headed. This is called the "drift angle."

At sea, smoke bombs dropped upon the surface of the water may be used to determine drift angle, a knowledge of which is essential for accurate navigation.

CONCLUSION

At the present time we find the development of the airplane and its engine still progressing at a rapid rate. We find in actual use:

Air transport club cars and sleepers.

Flying boats which are virtual ocean liners, with intercommunicating telephone systems, carrying one hundred passengers, with a crew of twenty-six, and capable of cruising six thousand miles at two hundred miles per hour.

Four-engine aircraft for land and sea.

Successful helicopters that can move at a comfortable speed either forward or backward.

Two engines geared to a single propeller for safety purposes.

Airplanes that can be flown by a novice after only a few minutes of instruction.

Flaps or air breaks which materially reduce landing speeds.

Air-cooled engines rapidly approaching two thousand horsepower with weights decreasing well below one pound per horsepower.

Constant speed propellers.

New types of low resistance cowling for aircooled engines.

Automatic pilots and blind landing devices.

Absolute altimeters.

"Duble-check" instrument board which automatically calls to the pilots attention any instrument not reading correctly.

And so the dizzy pace goes on. What will tomorrow bring?

Waiting for solution are many pressing problems such as the production of a satisfactory ice control to prevent the freeze-up of control surfaces at high altitudes. It has been suggested that exhaust heat from the engine be used for solution of this problem.

The problem of flight in the stratosphere is one which the industry is rapidly solving, and at the present time a number of experimental airplanes are being flown in the stratosphere and problems involving oxygen supply, superchargers, propellers, etc., are gradually being solved.

Design theories for more accurate design of skin-stressed airplanes are urgently needed as are also the following:

Absolute ground speed indicators to inform the pilot of his exact speed over the surface of the earth.

Blind landing arrangements, although fairly satisfactory, are still quite complicated and must be simplified.

Static caused by snow and ice on the antenna still interferes with reception and must be eliminated.

Satisfactory methods of using flush type rivets for attaching aluminum skin surfaces must be developed in order that skin resistance may be reduced.

Flat engines which may be placed inside the wing would materially increase speed. The industry is now waiting for such an engine.

It is not easy to predict the future of an industry advancing in this rapid fashion. Only of this may we be sure--that progress will continue, spurred on by man's desire to make flying more useful, comfortable, economical and safe.

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